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ARMSTRONG LABORATORY

THE SUBSTITUTION OF IVD ALUMINUM FOR CADMIUM, PHASE III

V.L. Holmes, J.J. Reilly

McDonnell Aircraft Company
McDonnell Douglas Corporation
Post Office Box 516
St. Louis MO 63166-0516

ENVIRONICS DIRECTORATE
139 Barnes Drive, Suite 2
Tyndall AFB FL 32403-5323

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This report has been reviewed and is approved for publication.

Ray A. Smith

RAY A. SMITH, 2Lt, USAF
Project Manager

Michael G. Katona

MICHAEL G. KATONA, PhD
Chief Scientist, Environics Directorate

Edward N. Coppola

EDWARD N. COPPOLA, Major, USAF
Chief, Environmental Compliance Division

Neil J. Lamb

NEIL J. LAMB, Colonel, USAF, BSC
Director, Environics Directorate

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V. L. Holmes, J. J. Reilly

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McDonnell Aircraft Company
McDonnell Douglas Corporation
P.O. Box 516
St. Louis, MO 63166-0516

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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Armstrong Laboratory Environics Directorate (AL/EQ)
Attn: Lt. Phillip Brown (AL/EQS)
Suite 2, 139 Barnes Drive
Tyndall Air Force Base, Florida 32403-5319

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13. ABSTRACT (Maximum 200 words)

The U.S. Air Force is concerned about the use of toxic processing at the Air Logistics Centers (ALCs). As part of their task to reduce hazardous waste production, they contracted the McDonnell Aircraft Division (MCAIR) of McDonnell Douglas through EG&G Idaho, Inc. to demonstrate that IVD aluminum coating can replace the various cadmium processes across-the-board at the ALCs. The IVD aluminum coating and process are environmentally clean and produce no hazardous waste. Both cadmium and the cadmium processes involving electroplating are toxic and require hazardous waste disposal.

In Phase I of this contract, technical information providing a comprehensive comparison between IVD aluminum and cadmium processing was compiled into a data base handbook for use by ALC personnel. Also in Phase I, MCAIR determined that IVD aluminum could replace cadmium processing without concern for about 80 percent of the ALC parts.

14. SUBJECT TERMS

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In Phase II, data was generated and process development was directed at "area of concern" applications. These included coverage of internal surfaces, lubricity, and, to a lesser extent, erosion resistance. A state-of-the-art IVD aluminum coater was also procured during Phase II for a Phase III demonstration of the applicability of the IVD aluminum process to be conducted at the WR-ALC.

In the current Phase III which completes the contract, MCAIR used a "hands-on" approach to demonstrate the applicability of IVD aluminum at the WR-ALC. The use of IVD aluminum was fully implemented for all parts that had previously been plated with cadmium at WR. During this period, the WR cadmium plating line was closed on a permanent basis. MCAIR also assisted the efforts of the other four ALCs to implement the use of IVD aluminum during a 2 week "hands-on" visit to each facility.

PREFACE

This report was prepared by McDonnell Aircraft Company (MCAIR), P.O. Box 516, St. Louis, MO 63166-0516, as part of Phase III of Contract C87-101602, "Demonstration of Ion Vapor Deposited Aluminum Coatings." The program was conducted by the Materials, Processes, Producibilty and Standards Engineering Department at MCAIR, St. Louis. The program was administered by EG&G Idaho, Inc. for the Armstrong Laboratory Environics Directorate (AL/EQ), Tyndall Air Force Base, Florida 32403. Lt. Phillip Brown (AL/EQS) was the Government technical and administrative program manager. This report summarizes work accomplished between 5 July 1991 and 31 August 1992.

EXECUTIVE SUMMARY

A. OBJECTIVE: McDonnell Aircraft Company (MCAIR) conducted Phase III of the three-phase program "Demonstration of Ion Vapor Deposited Aluminum Coatings" to demonstrate that Ion Vapor Deposited (IVD) aluminum coatings can replace toxic cadmium processing and reduce hazardous waste production at the Warner Robins Air Logistics Center (WR-ALC). The Phase III program was started on 5 July 1991 and was completed on 31 August 1992.

B. BACKGROUND: The IVD aluminum coating is soft and ductile with properties virtually identical to those of pure aluminum. Extensively tested in both laboratory and in service, it has been verified as a high performance, environmentally clean, corrosion resistant finish.

Cadmium, on the other hand, is a heavy metal and is toxic to humans. Once it escapes into the environment it can find its way into the water supply or food chain. Also, electroplated cadmium processing presents additional hazards associated with cyanide products in the plating bath. Therefore, an environmentally acceptable replacement will eliminate costs associated with ratchetting environmental regulations and hazardous waste collection, storage, disposal, and record keeping.

The Armstrong Laboratory Environics Directorate contracted MCAIR through EG&G Idaho, Inc. to demonstrate that IVD aluminum can replace cadmium across-the-board at the Air Logistics Centers (ALCs). The three-phase program entailed:

- Phase I - Data Compilation and Process Evaluation
- Phase II - Procurement and Research and Development
- Phase III - Demonstration

In Phase I, the IVD aluminum and cadmium processes were compared in the areas of cost, function, and effect on the environment. These comparisons were compiled into a data base handbook which provides the designer with a readily accessible technical database to justify the substitution of IVD aluminum for cadmium for most ALC applications.

Phase I of the program also determined that IVD aluminum can immediately replace cadmium without concern for approximately 80 percent of the parts. Parts which exhibit "areas of concern" were identified. These are ALC applications where either IVD aluminum by itself is not an adequate replacement for cadmium or where insufficient data exists. They include coverage of internal surfaces, lubricity, and to a lesser extent, erosion resistance.

During Phase II, MCAIR demonstrated the effectiveness of both sacrificial-type and barrier-type supplemental protection systems for internal surfaces. Torque-tension data was generated for ALC applications involving threaded engine hardware and wheel tie-bolts which demonstrated the acceptability of the use of IVD aluminum with proper lubrication. MCAIR suggested that a thicker IVD aluminum be used where feasible for erosive applications.

C. SCOPE: MCAIR demonstrated the acceptability of IVD aluminum to replace cadmium processing for detail parts at the WR-ALC. In additional, assistance was provided the Oklahoma City, Ogden, Sacramento, and San Antonio ALCs to implement the use of IVD aluminum coatings thereby reducing hazardous waste generation at the other ALCs.

D. METHODOLOGY: MCAIR employed a "hands-on" approach working with the responsible departments at the WR-ALC to replace the use of cadmium with the use of IVD aluminum for all parts that were cycled through the WR plating shop during a 12-month period. "Hands-on" coordination with responsible departments was used successfully to implement the usage of the then new IVD aluminum coating process at MCAIR.

E. TEST DESCRIPTION: Phase III consisted of six tasks. The first five tasks were directed at the replacement of cadmium with IVD aluminum at the WR-ALC by: assuring all processing equipment needs were available; defining thickness classes and processing steps; establishing Quality Assurance guidelines and tests; verifying environmental compliance; and demonstrating the feasibility of applying IVD aluminum to all parts that had been processed with cadmium. At WR-ALC, close coordination between MCAIR and the Industrial/Chemical Processing, Manufacturing, Material Management, and Environmental Management personnel enabled the five tasks to be completed successfully. The sixth task provided limited assistance to the other ALCs in their effort to reduce the use of cadmium.

F. RESULTS: The use of IVD aluminum was fully implemented for all parts at WR that had been previously plated with cadmium. During February 1992, the WR cadmium plating line was closed on a permanent basis eliminating this hazardous waste stream and its associated problems. During 2 week "hands-on" visits to the other ALCs, MCAIR assisted their efforts to further implement the use of IVD aluminum by providing training and process demonstration addressing "areas-of-concern" with the use of IVD aluminum.

G. CONCLUSIONS: The environmentally compliant IVD aluminum process is a demonstrated, acceptable across-the-board replacement for the toxic cadmium process at WR-ALC. Moreover, IVD aluminum can be demonstrated as a replacement for cadmium processing at all Air Force ALCs and other applicable DoD installations.

H. RECOMMENDATIONS: It is recommended that the remaining Air Force ALCs utilize the IVD aluminum coating process to its maximum extent to eliminate/reduce cadmium processing. Procedures for specialized applications should be established for IVD aluminum and for other suitable alternate corrosion protections systems for the elimination of cadmium plating at Air Force ALCs and other applicable DoD installations.

In addition, it is recommended that the ALCs implement the usage of non-chromated conversion coating to replace the currently used chromated conversion coatings due to stringent current and pending environmental regulations. However, potential replacement solutions must not compromise the functional performance of the IVD aluminum coating.

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SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of Phase III of this program is to demonstrate that Ion-Vapor-Deposited (IVD) aluminum can replace cadmium processing across-the-board at the Warner Robins Air Logistics Center (WR-ALC). Phase III completes an overall program to verify the applicability of IVD aluminum as a replacement for cadmium processing at the Air Force ALCs. Whereas cadmium has been widely used as a corrosion-resistant finish on steel, the substitution with IVD aluminum provides acceptable or improved performance in virtually all applications. More important, the substitution will make a major contribution to reducing hazardous waste production and its associated adverse effect on the environment.

B. BACKGROUND

Both the aluminum coating and the IVD process are environmentally clean. Cadmium, on the other hand, is a heavy metal and is toxic to humans. Once it escapes into the environment, it can find its way into the water supply or food chain. Also, electroplated cadmium processing presents additional hazards associated with cyanide products in the plating bath. On the economic side, a suitable replacement can both reduce life-cycle costs and provide an immediate return on investment by eliminating costs associated with control technology required to meet ratcheting environmental regulations and with hazardous waste collection, storage, disposal, and record keeping.

There are inherent advantages to the substitution of IVD aluminum for cadmium, in addition to hazardous waste reduction. IVD aluminum outperforms cadmium in preventing corrosion in acidic environments and actual service tests. Also, aluminum coatings can be used at temperatures up to 950°F, whereas cadmium is limited to 450°F. IVD aluminum coatings can be applied to high-strength steel without fear of hydrogen embrittlement. Aluminum coatings can be used in contact with titanium without causing solid metal embrittlement, and they can also be used in contact with fuels; cadmium is prohibited for these applications. Additionally, IVD aluminum can be used in space applications, whereas cadmium is limited because of sublimation.

The IVD aluminum coating is applied in production coating equipment called Ivadizers[R]. The basic equipment consists of a steel vacuum chamber, a pumping system, fixturing to hold the parts, an evaporator power supply, and a high-voltage power supply (Figure 1).

The IVD processing sequence consists of pumping the vacuum chamber down to about 9×10^{-5} Torr. The chamber is then backfilled with argon gas to about 1.0×10^{-2} Torr, and a high negative potential is applied between the parts being coated and the evaporation source. The argon gas becomes ionized and creates a glow discharge around the parts. The positively charged gas ions bombard the negatively charged surface of the parts and performs a final cleaning, which contributes to good coating adhesion.

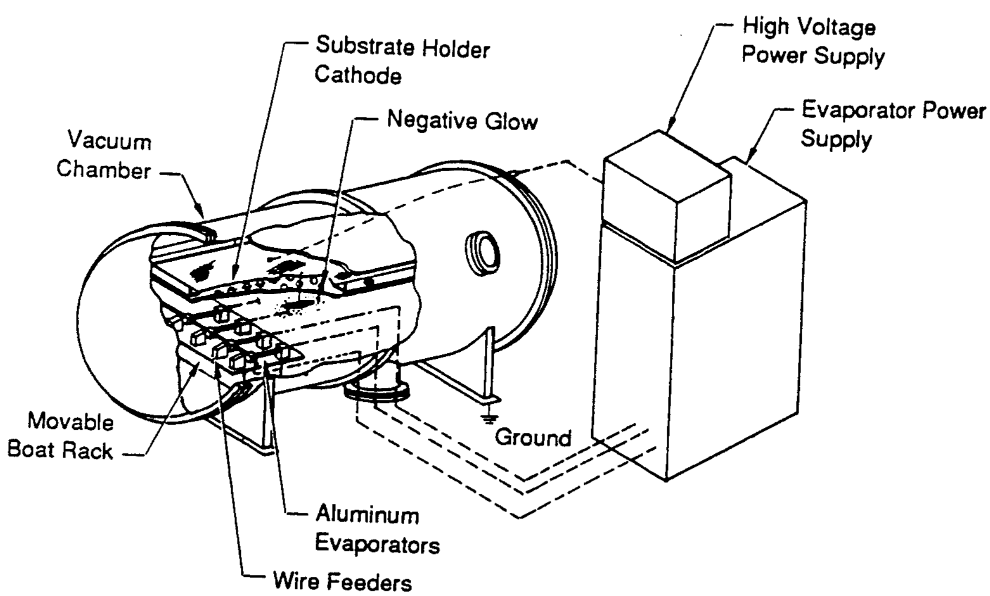


Figure 1. Schematic of an Ion Vapor Deposition System.

Following glow discharge cleaning, aluminum wire is evaporated by being continuously fed into resistance-heated crucibles. As the aluminum vapor passes through the glow discharge, a portion of it becomes ionized. This, in addition to collision with the ionized argon gas, accelerates the aluminum vapor towards the part surface, resulting in excellent coating adhesion and uniformity.

The coating requirements for IVD aluminum are specified in MIL-C-83488, the triservice specification for pure aluminum coatings. After coating, the parts are chromate-treated in accordance with MIL-C-5541. This provides additional protection against corrosion, forms a good base for paint adhesion, and is a common treatment for aluminum-alloy and cadmium-plated surfaces. In virtually all applications, IVD aluminum can replace cadmium of equal thicknesses. It can also be applied thicker than cadmium where part tolerance permits; this results in additional corrosion resistance.

The Air Force Civil Engineering Support Agency (CESA) has contracted the McDonnell Aircraft Company (MCAIR) through EG&G Idaho, Inc. to demonstrate that IVD aluminum can replace cadmium across-the-board at the ALCs. The thrust of the program is to reduce hazardous waste production.

MCAIR has now completed all the phases of the planned three-phase program. This report addresses Phase III proceedings. The three phases are:

Phase I - Data Compilation and Process Evaluation
Phase II - Procurement and Research & Development
Phase III - WR-ALC Demonstration

In Phase I, the technical information which provided a comprehensive comparison of the performance of IVD aluminum and the performance of the cadmium processes was compiled into a data base handbook, "The Substitution of IVD Aluminum for Cadmium" (Reference 1), "Bright", low-embrittlement, vacuum, and diffused nickel-cadmium processes were compared with IVD aluminum in several different corrosive environments. The versatility of the IVD aluminum coating and rework procedures were also included. In addition to the technical data presented, processing costs are addressed and an environmental impact study is provided. This provides the designer with a readily accessible technical database to justify the substitution of IVD aluminum for cadmium for most ALC applications.

Through a review of aircraft parts now processed with cadmium at the five ALCs, Phase I of the program also determined that IVD aluminum can immediately replace cadmium without concern for approximately 80 percent of the parts. Parts which exhibit "areas of concern" were identified. Phase II addressed "areas of concern." These are ALC applications where either IVD aluminum by itself is not an adequate replacement for cadmium or where insufficient data exists. They included coverage of internal surfaces, lubricity, and to a lesser extent, erosion resistance.

During Phase II, MCAIR demonstrated the effectiveness of both sacrificial-type and barrier-type supplemental protection systems for internal surfaces. Torque-tension data was generated for ALC applications involving threaded engine hardware and wheel tie-bolts which demonstrates the acceptability of the use of IVD aluminum with proper lubrication. MCAIR suggested that a thicker IVD aluminum coating be used where feasible for erosive applications. Where thickness tolerance is critical, MCAIR demonstrated improved erosion resistance with the use of an aluminum-alloy evaporant containing 12 percent silicon. This information is included in the Phase II final report (Reference 2). As with the Reference 1 report, the designer is provided technical data which addresses the limited "areas of concern" associated with the use of IVD aluminum.

MCAIR also supported the procurement and acceptance of a state-of-the-art IVD aluminum coater for the WR-ALC during Phase II. MCAIR prepared the procurement specification, conducted preliminary acceptance testing of the coater at a subcontractor site and final acceptance testing at WR, and trained WR personnel.

The Phase II WR coating system includes several items designed to improve productivity. They include:

- o Parts-holding racks/barrels designed for: larger parts that are hung stationary while being coated; larger parts that are rotated while being coated; and smaller parts that are rotated in barrels while being coated.

- o A fixture designed for the C-130 Barrel Hub to be used in conjunction with the rotary parts-holding rack to both hold the barrel hub and mask areas of the hub which are not to be coated.

- o Additional pumping capability that basically reduces the pumpdown portion of the IVD aluminum coating cycle by 50 percent or more. The cryopump system is used in conjunction with the conventional mechanical and diffusion pumping systems.

C. SCOPE/APPROACH

Phase III activities demonstrated the applicability of IVD aluminum as an across-the-board replacement for all detail parts that had previously been processed with cadmium at WR.

MCAIR employed a "hands-on" strategy at the WR-ALC to implement the usage of IVD aluminum. "Hands-on" coordination with responsible departments had been used successfully to implement the usage of the IVD aluminum process at MCAIR when it was a new process.

During Phase III, MCAIR:

- o Reviewed and coordinated supporting processing needs such as part precleaning, special coater hooks and fixtures to increase throughput, post-coat processing, and supplemental processing.

- o Reviewed authorization documentation, drawings/parts, defined coating thickness classes, identified supplemental processing needs, and reviewed the WR process specification.

- Reviewed and defined acceptance performance requirements, test procedures, and equipment needs.

- Assisted WR in demonstrating the feasibility of applying IVD aluminum to WR detail parts that had been processed with cadmium. This effort included establishment of production procedure cards for individual detail parts to promote repeatability. Productivity gains attributable to the use of a state-of-the-art coater and a special holding fixture for the C-130 Propeller Hub were established.

- Verified environmental compliance progress with WR Environmental Engineering.

- Provided limited assistance to the other four ALCs to help meet the ultimate goal of the elimination of cadmium processing at all of the ALCs.

SECTION II

SUPPORTING PROCESSING NEEDS

A. SUMMARY

Successful implementation of the IVD aluminum process at any facility such as the WR-ALC requires the proper supporting processes and equipment. Supporting processes and equipment required for the IVD aluminum process include part precleaning, special hooks and fixtures, post-coat processing, and supplemental processing. The use of proper equipment, material, and procedures enable parts to be: 1. properly precleaned for IVD aluminum coating; 2. properly fixtured to the IVD coater parts-hanging rack and/or masked with vacuum/temperature compatible materials; 3. properly peened with glass beads after coating to check coating adhesion; 4. properly chemically conversion coated to enhance corrosion resistance and to provide a base for paint adhesion; and 5. properly supplementally processed if required (i.e., parts having cavities or recess areas can be supplementally coated for additional corrosion protection in these thin-coated areas). During Phase III, MCAIR reviewed current WR procedures and equipment, made recommendations, and helped with the design and/or procurement of items required for acceptable production and/or items designed to improve productivity. This task was completed successfully by close coordination between MCAIR and the WR's Production and Industrial/Chemical Process Engineering personnel.

B. TASK

MCAIR reviewed and coordinated supporting processing needs with Production and Industrial Engineering at the WR-ALC for the following items:

1. Part preclean processing
2. Special coater hooks, masks, and fixtures
3. Postcoat processing
4. Supplemental processing

1. Part Preclean Processing

a. Significance

Vacuum-system processes like IVD aluminum required high initial part cleanliness. Part surface contaminates outgas during the IVD aluminum coating cycle. The result is increased pumpdown time and a source of oxygen for reaction with the vaporized aluminum. Instead of a soft layer of aluminum being deposited, a hard, glassy layer of aluminum oxide is deposited which is detrimental to both coating adhesion and the sacrificial corrosion protection properties of the coating. Although the IVD aluminum coating process utilizes a cleaning step called "glow discharge cleaning," this cleaning step is not designed to replace proper precleaning. Also, careful part handling is required to prevent recontamination of cleaned parts from fingerprints and dirty shop environments.

Precleaning for IVD aluminum consists of a solvent clean to remove oil and grease-type contaminants followed by a mechanical or chemical clean to remove paint and sealant residues, corrosion products, rust, and oxides. Steel parts are grit-blasted; whereas, aluminum parts are either grit blasted or chemically cleaned by use of alkaline cleaning solutions, mild pickles, and deoxidizers.

The solvent preclean removes oil and grease from part surfaces. This is a critical step to prevent carryover of contamination products to the grit-blast media which in turn are transferred to the part to be coated. Localized contaminated areas will exhibit poor coating adhesion. WR uses a vapor decreasing process to solvent preclean.

Proper use of vapor decreasing equipment allows the part to be maintained in the solvent vapors in the degreaser. Condensation of the hot vapors on the cooler parts effectively washes oils off the part surface. Proper part orientation prevents condensate from collecting in recesses and cavities. Parts with cavities generally require supplemental cleaning. Wands that allow the condensed vapor-decreasing fluid to be directed into these areas are effective. Parts with faying surfaces or small openings in cavities are especially hard to clean. In addition to normal decreasing, these parts may require special probes to flush out oil and grease followed by a high temperature bake to carbonize any remaining oil or grease.

Following the vapor degrease step, WR completes precleaning with a grit blast process. Grit blasting media and equipment mechanically remove surface contaminants such as organic soils remaining after vapor decreasing, oxides, scale, rust, sealant and paint residue, and corrosion products. Since grit blasting abrasively removes metal at high pressures from the surface of the part, metal removal must be controlled to prevent part distortion, surface finish degradation, or detrimental part dimensional changes. Heavy steel parts are normally grit-blasted with 120 - 220 mesh aluminum-oxide grit at 60 - 90 psi. Aluminum-alloy and close tolerance parts (parts with dimensional tolerance controlled to 0.001 inch or less after IVD aluminum coating) are normally grit blasted with 220 mesh aluminum-oxide grit at 30 - 40 psi.

The conditions of parts at an overhaul facility are different than original equipment manufacturer (OEM) parts. The OEM parts are new and relatively clean. The parts being reworked at the overhaul facility may have relatively rough surfaces, may have paint residue or sealant in holes and recesses, be greasy or oily, and may contain corrosion sites. This necessitates close attention to shop stripping and cleaning procedures and vigorous but controlled grit-blasting to produce clean parts.

b. Progress

WR employs vapor decrease/mechanical clean steps to preclean parts prior to IVD aluminum coating. The acceptability of preclean procedures/equipment was verified by visual examination of parts after each cleaning step. The ultimate acceptability is consistent, acceptable coating adhesion which is the norm at WR.

o <u>Vapor Degreaser/Solvent</u> - WR uses 1,1,1 trichloroethane (TCA) which is an acceptable vapor-degrease solvent. Their vapor decrease tanks equipped with vapor condensing coils and hoist are adequate for the application. NOTE: TCA is an ozone layer depleting source and its future use will be prohibited. This issue is addressed in Section V.

Some parts such as the C-130 351902-1 center wing flap bolt require special processing to be cleaned sufficiently. The 1-inch diameter by 5-inch long bolt is hollow and packed with grease. The bolt contains a threaded hole for an alimite fitting on one end and a 0.06-inch hole in the center of the cylindrical section. Repeated vapor degreasing cycles did not remove all the grease. The WR plating shop designed a flushing probe which was connected to the vapor degreaser hand wand and inserted into the bolt to the bottom of the hollow, cylindrical cavity. With the special apparatus, all grease was removed resulting in acceptable coating adhesion. Prior to special cleaning, the coating adhesion on the bolt was poor.

Special processing at times requires a high-temperature bake. Oil is difficult to remove from small holes in parts and from parts with small openings which open into larger internal cavities. Oil will sometimes leach from these areas after degreasing. Parts may also contain paint or sealant residue left from paint stripping which block internal recesses. High-temperature baking is an effective means to remove these contaminates. High-temperature bake procedures were implemented at WR for the 3G11520-127 and -128 C-141 Bellcranks (internal cavities filled with MIL-C-11796, Class 1 corrosion prevention compound) and for the 3G10202-103 and -104 C-141 Main Landing Gear Bellcrank Assembly Links (paint/sealant residue in bolt and safety tie holes). The Bellcranks and Links are both being baked for several hours at 375^{O}F after decreasing. An additional vapor degrease before grit blasting is optional.

The Oklahoma City (OC) ALC utilizes this procedure effectively but in a slightly different manner. OC vapor-degreases, grit-blasts with 220 aluminum-oxide grit, and bakes the part at high temperatures for about 2 hours. The temperature is typically 600 - 800^{O}F, but at least 50^{O}F below the steel's heat-treat temperature. OC coats the parts without an additional grit blast step to remove the visible heat oxide. Although coating adhesion passes the 40 psi glass bead peening test, MCAIR is concerned about the effect of the underlying oxide and recommends grit blasting after baking until the effect of the oxide on corrosion resistance is evaluated.

At WR, neither the IVD operator nor the grit blast operator had the assigned responsibility to vapor-degrease the parts before grit blasting. The IVD operators, suspicious of contaminated parts from either no vapor degreasing or improper part handling, usually added an extra vapor-degrease cycle between grit-blasting and IVD aluminum coating to assure part cleanliness. MCAIR and WR management implemented procedures and responsibilities to both improve and eliminate unnecessary part handling. See Figure 2.

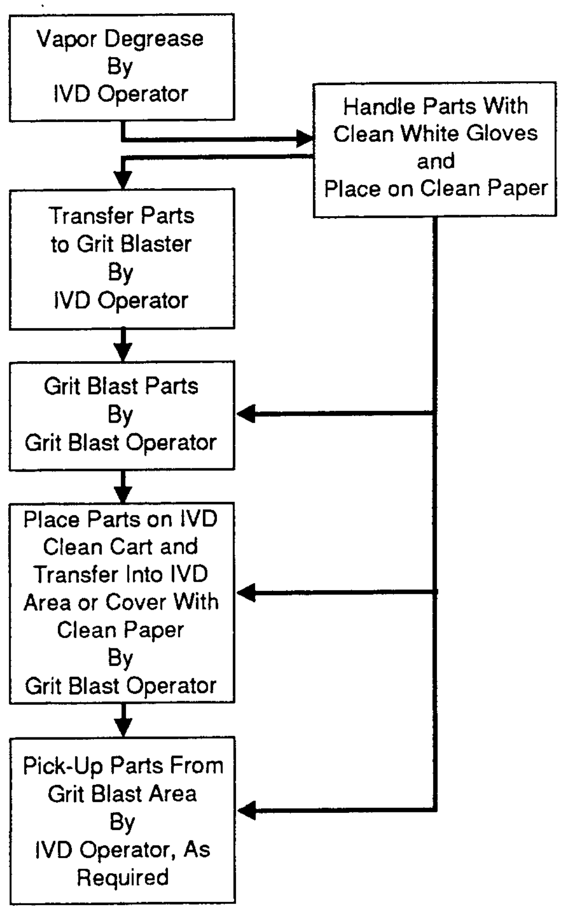


Figure 2. Part Preclean Flowchart.

o <u>Grit Blaster/Grit Media</u> - WR generally uses large walk-in, pressure type grit blasters for ease of part movement. These blasters deliver a large flow rate of grit media through a 1/2-inch nozzle. WR cleans steel with either aluminum oxide (180 mesh) per MIL-A-21380 or sand (20-50 mesh) per MIL-S-17726 blasting media at 90 psi in a manual mode. Grit blasting with the coarser sand speeds cleaning but produces a rougher surface finish. Adhesion of the aluminum coating to both sand and aluminum-oxide-cleaned parts has been excellent. The corrosion resistance of parts cleaned with sand versus aluminum oxide was tested acceptably to the requirements of MIL-C-83488. The WR equipment, media, and procedure are acceptable for handheld, structural steel details that are not tolerance-critical.

The large walk-in grit blaster is inappropriate, however, for blasting close tolerance parts (dimensions controlled to 0.0010 inch or less). The blaster/nozzle combination delivers too aggressive an abrasive stream of media. Dimensional tolerances were not maintained on fasteners due to excessive metal removal. The metal removal rate was excessive even with 180 mesh aluminum oxide grit at pressures as low as 40 psi.

o Cabinet-type grit blaster - The use of a cabinet-type grit blaster with a small nozzle, low grit-blasting pressure, and 180 or smaller mesh aluminum-oxide grit was implemented. Under these conditions, the abrasive stream of media cleans without a high metal removal rate.

WR is now manufacturing fasteners to counter slow delivery from fastener manufacturers for small and/or odd-lot orders. MCAIR assisted their effort to replace cadmium with IVD aluminum for this application. Fasteners should be tumbled during the grit blast, IVD aluminum coat, glass-bead peen, and chemical conversion coat steps to achieve higher quality coatings and to improve productivity. MCAIR provided barrel accessory information to WR for their cabinet-type grit blaster (Reference 3). NOTE: The state-of-the-art IVD aluminum coater installed at WR during Phase II of this program includes a dual-barrel accessory. The barrel accessory can accommodate up to 300 pounds of fasteners during one coating cycle.

Aluminum oxide was recommended to WR for cleaning all aluminum alloy parts and close tolerance threaded parts. The 180 grit produces a smoother surface than sand. Smoother surfaces reduce hardness reading scatter when testing aluminum-alloy parts. Dimensional tolerances are maintained by grit blasting with 180 grit at 30 - 40 psi using a grit blast nozzle with a 0.25-inch or smaller opening.

2. Special Coater Hooks, Masks, and Fixtures

a. Significance

Hooks are used to attach parts to the IVD coater parts-hanging racks for coating. Fixtures are used to selectively mask surface areas from coating and/or for attachment to the parts-hanging rack. Tapes and foils are also used for selective masking. Proper use/selection of these items is critical to both coating quality and productivity.

Hooks are used to suspend parts from a heavy wire-mesh grid (screen) on the stationary parts-hanging rack as shown in Figure 3. They also provide the necessary electrical contact between the parts and screen to maintain the parts at the proper negative potential during glow discharge cleaning and coating. They are designed with a small radius to fit within the diamond pattern of the screen. This generally requires fabrication from wire stock 1/8 to 3/16 inch in diameter. A "J" shaped hook with the end slightly grounded to dull the point is the best configuration. This configuration allows coating to wrap around and under the hook, leaving only a small point contact area on the part that is void of coating. Most hook contact areas do get coated because most parts are turned over and recoated for proper coating uniformity and because the IVD process results in coating wraparound onto the back side of the parts. IVD aluminum coating buildup is easily removed or stripped from hooks with a sodium hydroxide/water solution. The use of stainless-steel hook material requires only stripping, rinsing, and drying before reuse.

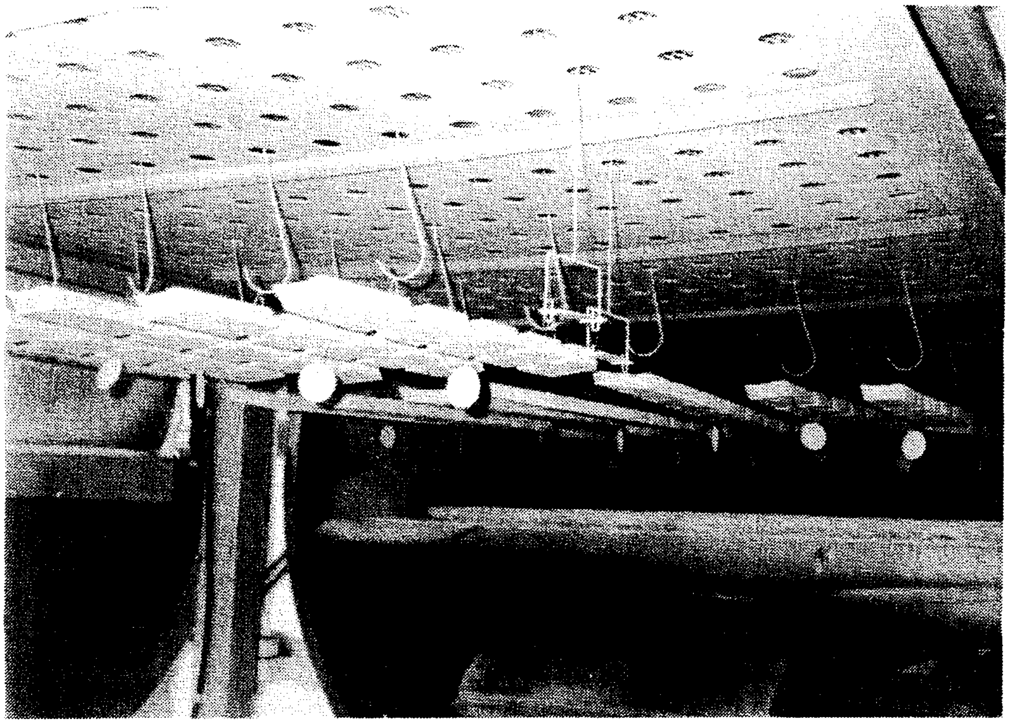


Figure 3. Suspension of Parts From Stationary Parts Rack With "J" Hooks.

Masking is used to selectively prevent part surfaces from being coated. Also, masking of Class 3 coated threaded areas is required during transition from a Class 3 to a Class 1 coating for non-threaded areas. Threaded areas are normally Class 3, 0.0005 inch thick maximum, for torque-tension and dimensional tolerance considerations. MCAIR recommends Class 1 coatings, 0.001 inch thick minimum, for maximum corrosion resistance.

Hard metal (reusable) masks and metal foil are recommended for selective masking when possible. Stainless steel is the preferred material for reusable masks. Only special tapes can be used to mask parts. Unlike the low temperature cadmium electroplating process where tapes are effective, part temperature during IVD aluminum coating can reach $300^{0}F$ or more when temperature control is not required. During both glow discharge cleaning and coating, the parts are heated by the bombardment of the argon ions. During coating, the parts are additionally heated by the condensation of the vaporized aluminum onto the part. Tapes approved for the IVD coating process must withstand $300^{0}F$ without deterioration. The tape adhesive must not start to decompose under $300^{0}F$, outgas into the vacuum system, or be difficult to remove from or leave adhesive residue on the coated part. Although limited in numbers, there are tapes that satisfy these restraints (Reference 4). The use of tapes for masking small or thin steel parts is not recommended unless part temperature is controlled by alternate coating/cooling cycles which is standard practice for processing aluminum alloy parts. Even the best tapes outgas when part temperature exceeds $300^{0}F$ leading to discolored parts and potential adhesion problems.

Masking parts for cadmium plating requires no special techniques for applying the tape. Tape applied to parts for IVD aluminum must be applied tightly and uniformly to the part without trapping air bubbles under the tape. Air bubble expansion during coater evacuation further lifts the tape off the part. Since the portion of the tape over the air bubble(s) is not heat-sinked to the underlying metal part, the tape/adhesive over the air bubble(s) rapidly heats and bursts from the heating effect of the condensing aluminum vapor. The escaping air and adhesive decomposition products are a source of oxygen for reaction with the vaporize aluminum. Instead of a soft layer of aluminum being deposited, a hard, glassy layer of aluminum oxide is deposited often resulting in localized coating adhesion failure (Reference 5).

b. Progress

During this period, a large selection of hooks and hangers was made by WR to handle the new array of part sizes and configurations being IVD-aluminum-coated. In addition, stainless-steel masks and fixtures were made to simplify masking and improve coating efficiency for parts coated with the stationary parts-hanging rack. Additional specialized fixtures were made to mask and attach C-130 rear propeller barrel halves to the rotary parts rack.

o Hooks and Hangers - Approximately 123 parts were changed from cadmium plate to IVD aluminum at WR. The wide variety and complexity of these parts necessitated an increase in the number and sizes of standard "J" hooks for attaching parts to the parts rack. "J" hooks from 4 to 12 inches long were made. Small double "J" hooks were made for use with specialized fixtures fabricated for C-141 main landing gear bellcrank assembly parts. Also, special hangers were made for hanging coating thickness, bend-to-break, and corrosion resistance test panels horizontally above the boats at the same elevation as the production parts.

o C-141 Main Landing Gear Bellcrank Assembly Fixtures - Alloy-steel fixtures that had been used for cadmium plating were modified for IVD coater use until new stainless steel fixtures became available. Forty stainless-steel ball fixtures for masking the lower and upper retainer halves and 20 stainless-steel enclosures for masking the ball shaft of the Main Landing Gear Bellcrank Assembly were designed, fabricated, and are functioning as intended. See Figure 4, and parts 9, 10, and 11 of item E in Figure 5. The number of the new stainless-steel fixtures provides WR additional handling capacity for these high volume parts. They also provide better masking and are easier to clean than the alloy-steel masks.

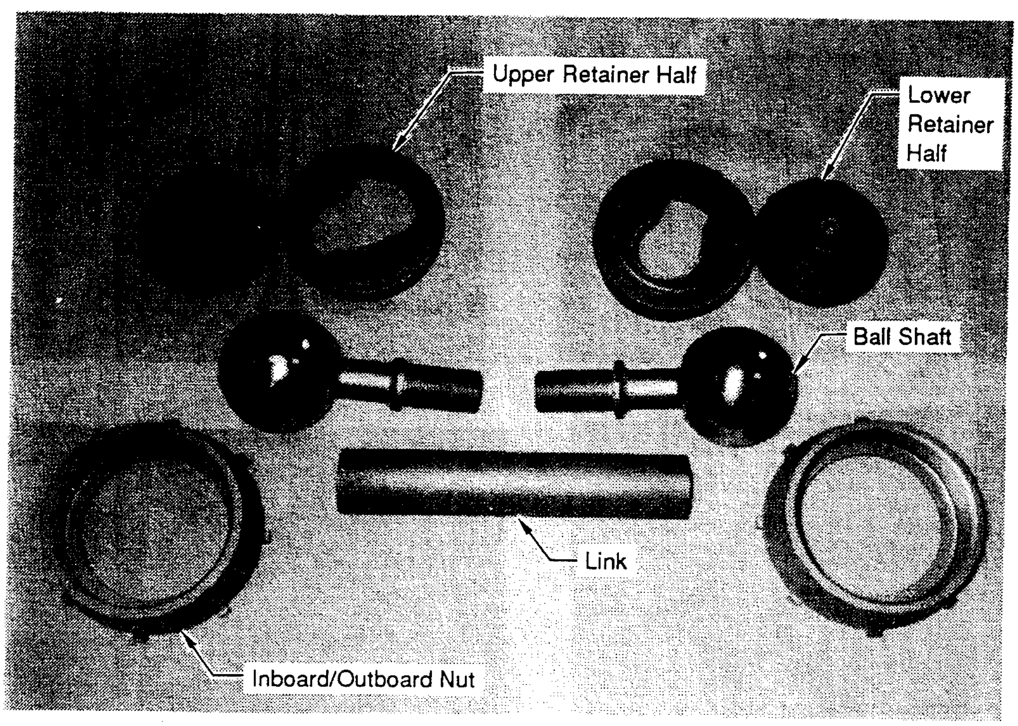


Figure 4. IVD Aluminum Coated Bellcrank Assembly Parts.

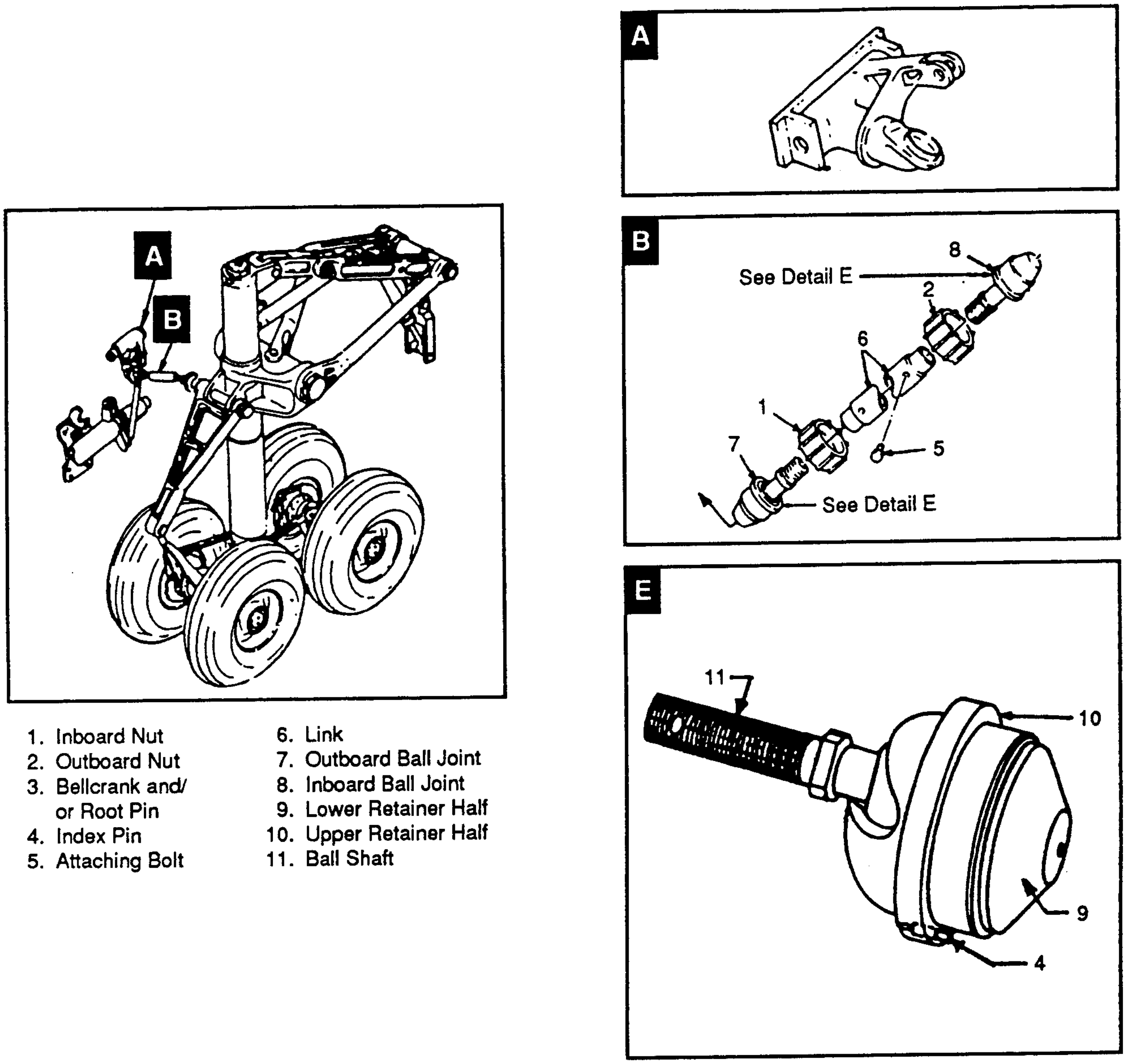


Figure 5. **C-141 Main Landing Gear Bellcrank and Bellcrank Assembly.**

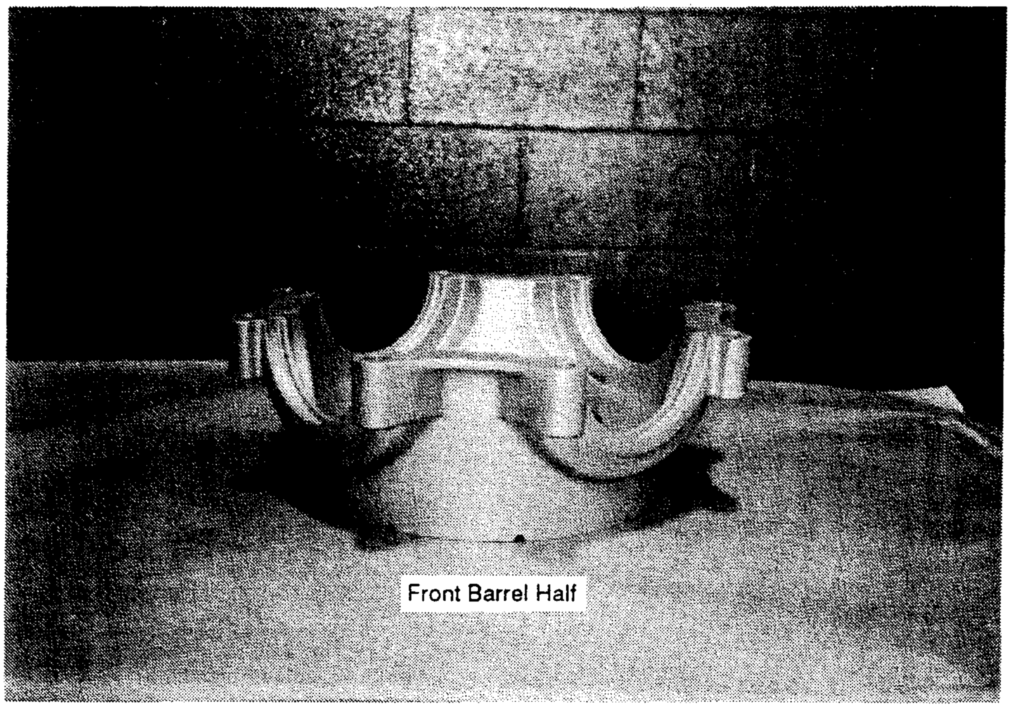
o C-141 Main Landing Gear Bellcrank - Masking requirements for the 3G11520 C-141 Main Landing Gear Bellcrank were implemented. A through hole in Detail A of Figure 4 and area adjacent to that hole had been masked for cadmium plating. A review of part usage revealed no need for masking. These areas are now IVD aluminum coated for protection against corrosion. A stainless-steel mask was designed and manufactured for a threaded extension on the bellcrank, Detail A of Figure 4. The bellcrank receives a Class 1 (0.001-inch thick minimum) coating except for the threaded extension area which receives a Class 3 (0.0003-0.0005 inch thick) coating. During the transition from a Class 3 to Class 1 coating, the threaded area is masked from additional aluminum coating.

o C-130 Propeller Rear Barrel Half Fixture - The C-130 Propeller Barrel Assembly is composed of two barrel halves, front and rear, shown in Figure 6. During Phase II of this program, MCAIR designed and fabricated a fixture for the rear barrel half which attaches the part to the rotary parts-holding rack and masks areas on the part which are not to be coated (Figures 7 and 8). This high-volume detail had been identified by WR as an application where special fixturing would improve productivity. To meet production demand, WR fabricated eight additional fixtures during Phase III of the program to facilitate eight parts coated simultaneously on the rotary parts-holding rack, Figure 9. The MCAIR-supplied fixture was used extensively to coat rear barrel halves until additional fixtures become available. WR has now processed groups of up to seven fixtured rear barrel halves.

Part of the fixture for the C-130 rear barrel half was also used as a mask during grit blasting and glass- bead peening. Since multiple use reduced its availability in the coating area, two simpler fixtures were fabricated for grit blasting/peening only.

A platform for supporting and aligning the fixtured rear barrel halves during loading onto the rotary rack was designed and fabricated by WR, Figure 10. The wooden platform, 106 x 28 x 8 inches, fits on top of a cart. An adjustable support (Figure 11) was added to the platform/cart to hold the fixtured barrel halves level during installation of the support drive rods through the fixtured barrel halves and into the rotary drive mechanism. It is now being effectively used. MCAIR also recommends the use of a scissors jack to help attach heavier parts to the stationary parts rack or for loading fixtured parts onto the rotary parts rack.

o Masking Materials - Since adhesive-backed masking tapes may outgas during the coating cycle unless coating/cooling cycles are employed, MCAIR



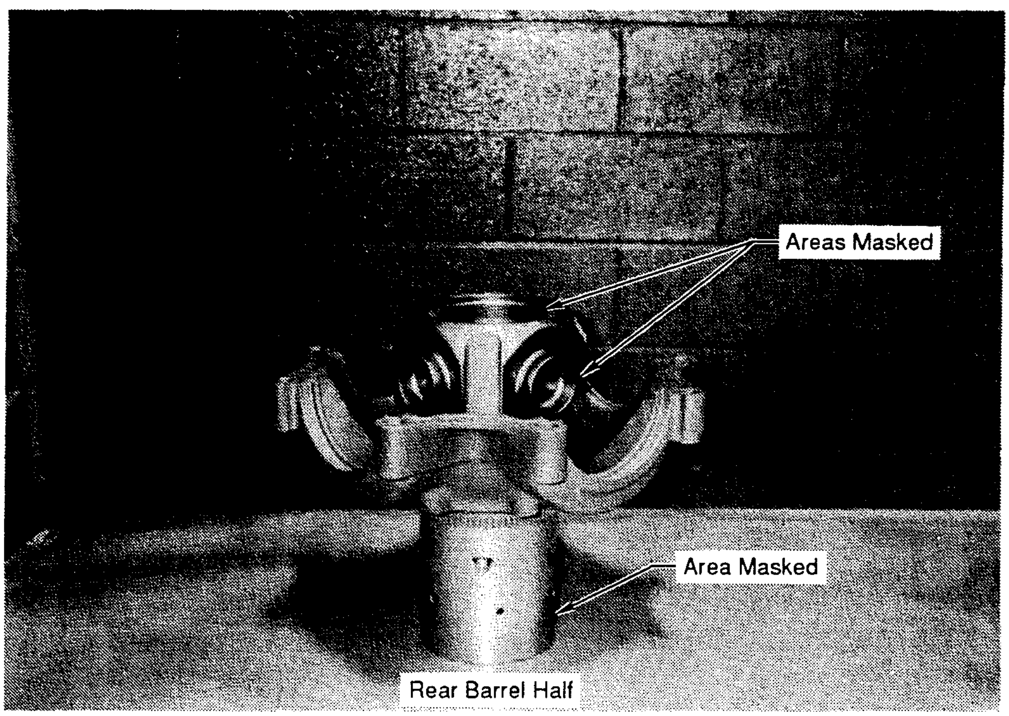


Figure 6. C-130 Propeller Barrel Halves.

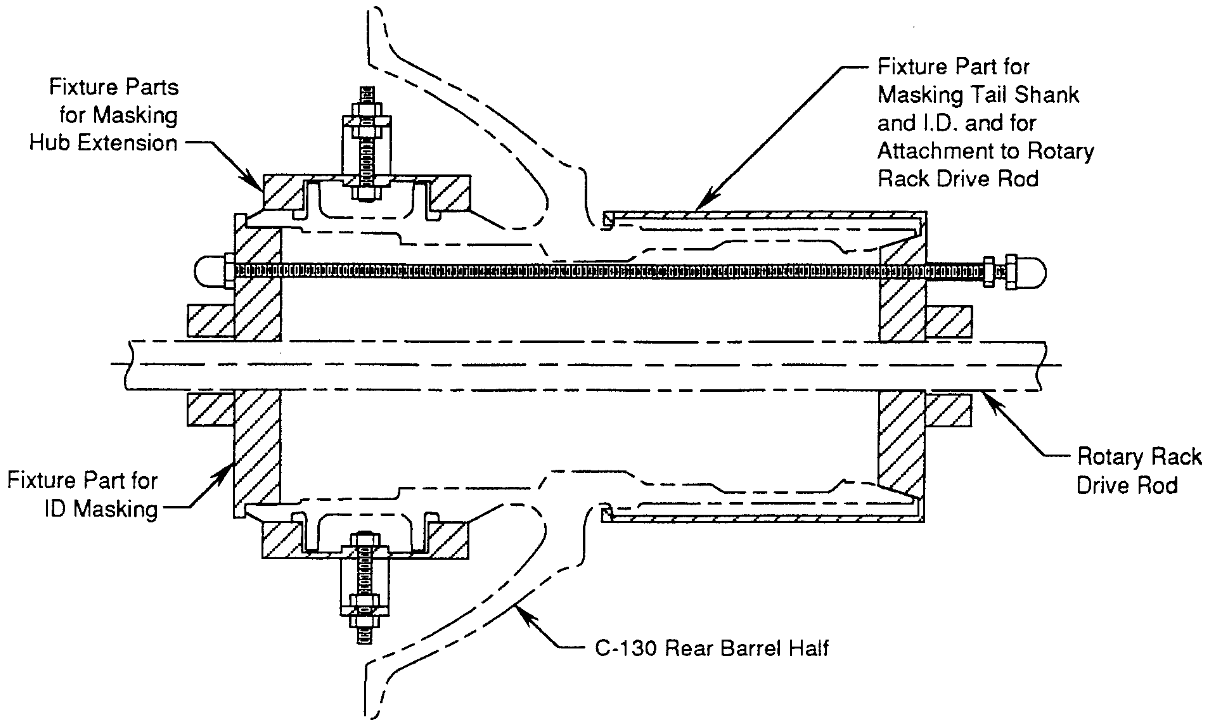


Figure 7. Fixture/C-130 Propeller Rear Barrel Half Installed on the Rotary Rack.

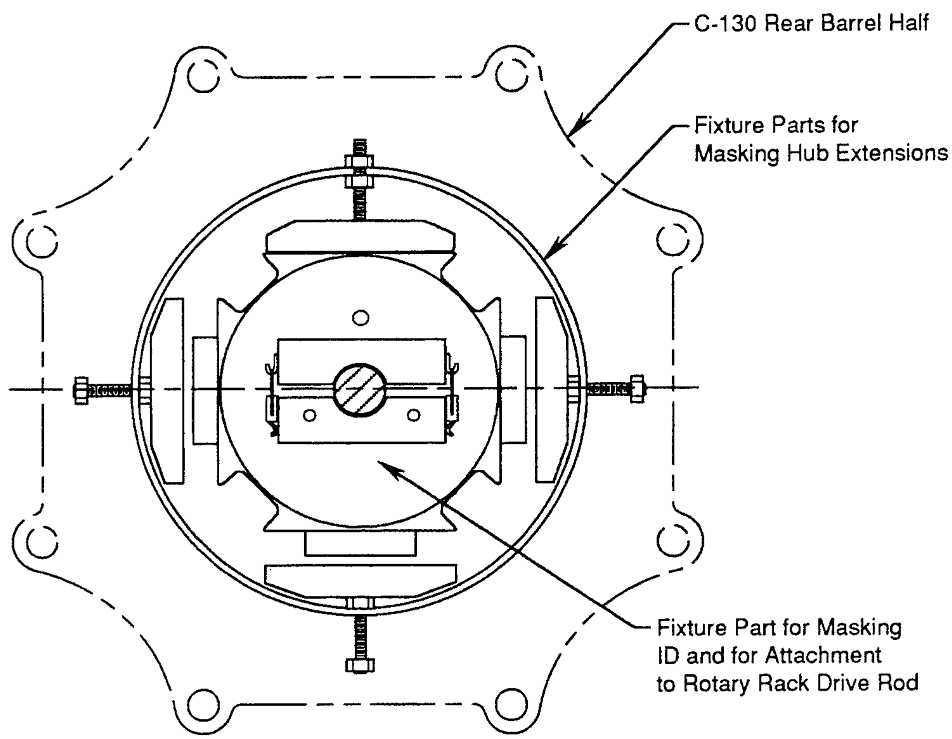


Figure 8. End View of Fixture/C-130 Propeller Rear Barrel Half Installed on the Rotary Rack.

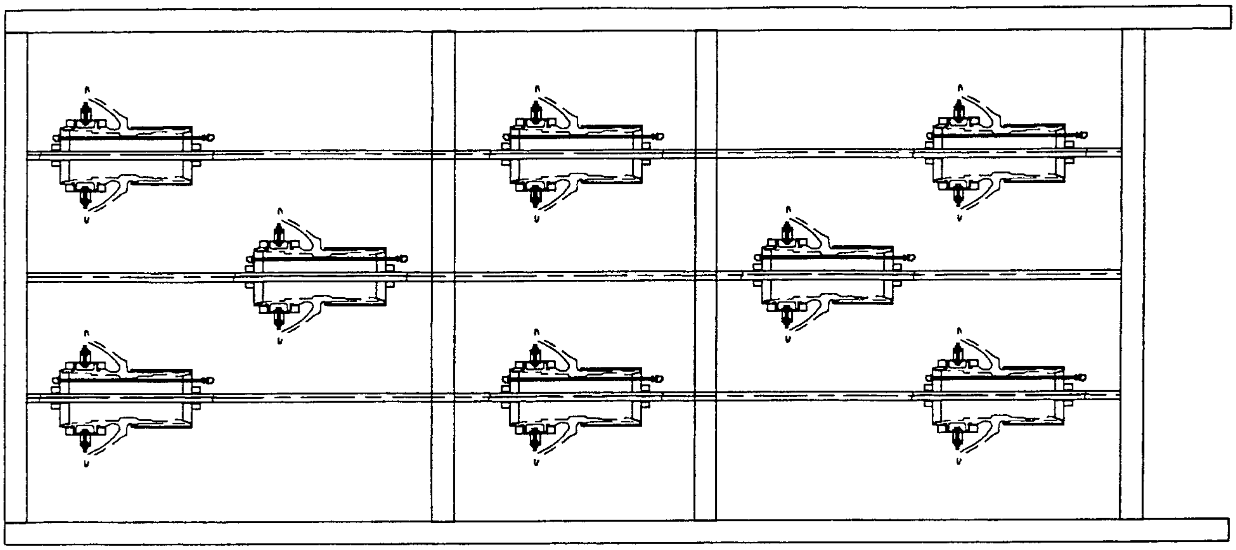


Figure 9. Concept for Installation of Eight C-130 Propeller Rear Barrel Halves on the Rotary Rack.

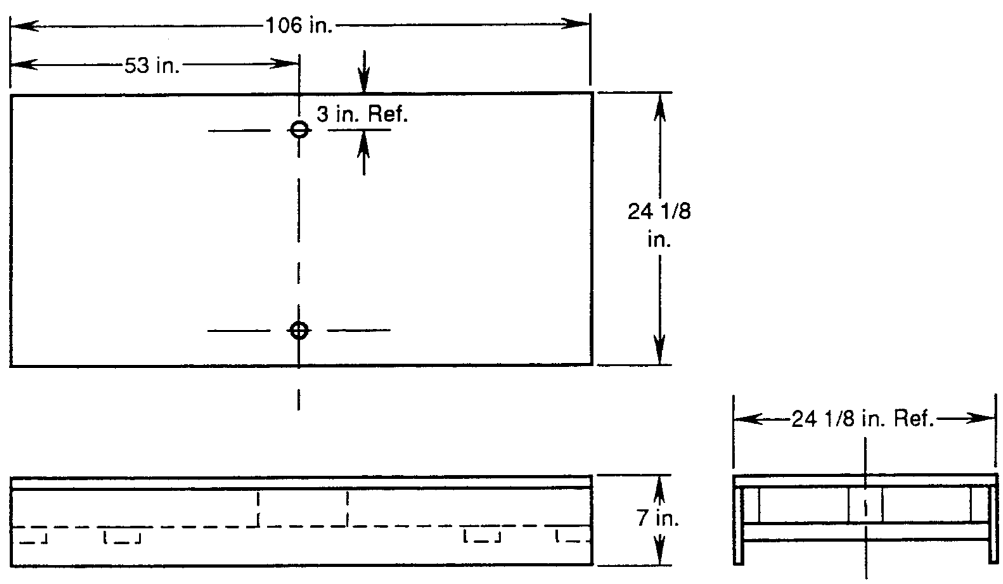


Figure 10. Platform For Supporting And Aligning Fixtured C-130 Propeller Rear Barrel Halves Onto The Rotary Rack.

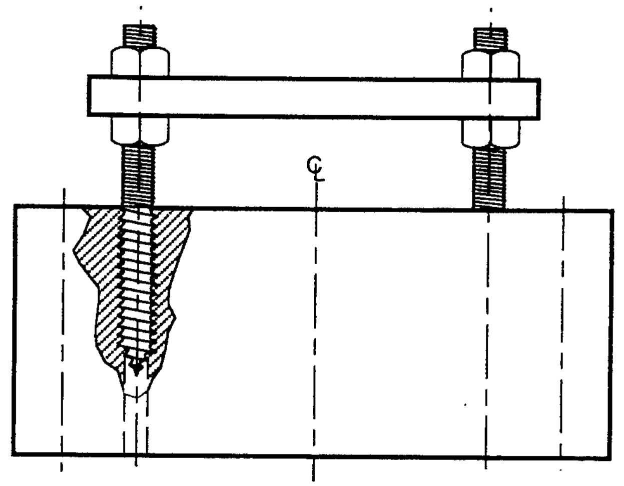


Figure 11. C-130 Barrel Half Support Assembly.

recommends their use be minimized. Aluminum and stainless-steel foils, or specifically configured stainless-steel masks are recommended to mask areas where the coating is not wanted. WR was provided source and cost data for aluminum and stainless steel foils (Reference 6).

o Wire Sources - WR requested a source list for the aluminum wire evaporant used during coating. Five aluminum wire sources that satisfy the MCAIR Material Specification for the aluminum wire were provided, Table 1.

3. Post Coat Processing

a. Significance

IVD aluminum-coated parts receive two post-coat processing steps; namely, burnishing or peening with glass beads, and a chromate conversion coat treatment. During the first step, IVD aluminum parts are glass bead peened to verify coating adhesion and to densify the aluminum coating for improved corrosion resistance. During the second step, the IVD aluminum-coated parts receive a supplementary chromate conversion treatment in accordance with MIL-C-

5541, Class 1A to improve corrosion resistance as well as to prepare the surface for acceptable paint adhesion.

TABLE 1. ALUMINUM WIRE SOURCES.

Source	Address/Telephone Number	
Arcola	Arcola Wire Beaver Road Branford, CT 06405	(203) 481-5381
Astrolite	Astrolite Alloys Corporation 4725 Calle Alto Camarillo, California 93010	(805) 484-3621
Lone Star Wire	Lone Star Wire Inc. 4824 Cash Road Dallas, Texas 75247	(214) 630-7976
Phifer Wire	Phifer Wire P.O. Box 1700 Tuscaloosa, AL 35403	(205) 345-2120
Shaped Wire, Inc.	Shaped Wire, Inc. 900 Douglas Road Batavia, Illinois 60510-2294	(708) 406-0800

MCAIR developed production equipment and was the first company to use the IVD aluminum coating process on a production basis. To assure consistent adhesion on production parts, MCAIR implemented glass-bead peening as a nondestructive inspection method that is performed rapidly, inspects 100 percent of the surface, and is a more severe coating adhesion evaluator than other methods like tape testing. For example, glass-bead peening at only 20 psi using number 10 glass beads detects unacceptable coating adhesion that tape testing misses. MCAIR considers peening at 40 psi to be comparable to bend-to-break coupon testing.

The glass-bead stream burnishes the aluminum coating while momentarily introducing stresses at the impingement site. An effective glass-bead peening procedure burnishes and stresses the aluminum coating sufficiently to reveal a weak coating bond without eroding the coating by controlling glass bead media size, pressure, and distance from the peening nozzle to the part. If the glass-bead size is too small, peening pressure is too low, or part-to-nozzle distance is too great, the coating may not be sufficiently stressed to detect poor coating adhesion. If the bead size is excessive, coating pressure too high, or the nozzle too close to the part, coating is eroded off part edges. The procedure MCAIR recommends uses number 10-13 glass beads, an inspection pressure of 40 psi, and slowly fans the glass-bead peening nozzle over the part at a part-to-nozzle distance of 6 - 8 inches.

MIL-C-83488 requires a Type II coating which receives a supplementary chromate treatment in accordance with MIL-C-5541, Class 1A unless otherwise specified. MIL-C-5541 specifies two classes of conversion coatings that are shown in Table 2.

TABLE 2. CLASSES OF CHROMATE CONVERSION COATINGS.

Class	Class Use
1A	For Maximum Protection Against Corrosion.
3	For Protection Against Corrosion Where Low Electrical Resistance Is Required.

Chromate conversion coatings are available that satisfy both classes. They should be applied within 24 hours of glass bead peening to obtain maximum corrosion resistance. Properly applied chromate conversion treatments can increase the corrosion resistance capability of the applied IVD aluminum coating by a factor of 10 or more (Reference 1).

b. Progress

Proper application of the glass-bead peening and chromate conversion post-coat operations was verified at WR by visual examination of parts for uniformity of application. Glass-bead peening is visually acceptable when a uniformly shiny part is produced before chemical conversion coating and uniform coloration produced after chemical conversion coating. A properly applied chemical conversion coating will exhibit a uniformly colored conversion film that is free from powdery or loose coating. Ultimate acceptability is consistent, acceptable corrosion resistance and paint adhesion. Both are the norm at WR.

o Glass-Bead Peener/Media - WR uses the same large walk-in type blasters for glass-bead peening as used for grit blasting. Separate blasters are used for grit blasting and glass-bead peening to assure that abrasive grit residue is not mixed with glass-bead media. The pressure-type equipment delivers a high flow rate of glass-bead media to the part through a 1/2-inch nozzle at a pressure setting of 40 psi. This media is #13 glass beads per MIL-G-9954. The WR equipment, media, and procedure are acceptable for peening hand-held details.

The adequacy of the WR procedure for handheld parts was verified both visually and with a simulated test. The peening procedure produced consistent, uniformly shiny parts. In the simulated test, two of four panels were contaminated with facial oil at fingerprint sites. All the panels were IVD aluminum coated and glass-bead peened at 40 psi. Localized coating non-adhesion did occur at the contamination sites.

The WR procedure is cumbersome for glass-bead peening large quantities of small parts, such as fasteners. Fasteners are recommended to be tumbled during the grit blast, IVD coat, glass-bead peen, and chromate conversion coat steps to achieve higher quality coatings and to improve productivity. MCAIR presented WR barrel accessory information for their walk-in peener (Reference 3).

o Chromate Conversion Coatings - The WR equipment consists of a solution tank, a cold water rinse tank, and a hot water rinse tank. WR uses a Turcoat Alumigold chemical conversion coating that is qualified to MIL-C-5541, Class 1A for maximum corrosion resistance. The WR equipment, solution, and procedure are acceptable for the chromate coat step. MCAIR did caution WR not to exceed 140^{O}F during the hot water rinse step. Temperatures above 140^{O}F have been shown to degredate corrosion resistance capabilities.

However, Turcoat Alumigold is not qualified as a Class 3 coating for low electrical resistance applications (Table 2). MCAIR recommended two solutions, Alodine 1200 and Iridite 14-2, that satisfy both MIL-C-5541 Class 1A and Class 3 requirements in the event future WR applications require a low electrical resistance surface for electrical bonding/electro-magnetic interference compatibility (EMIC) purposes.

MCAIR provided WR with information on a tumbling system to process large volumes of small parts like fasteners along with a spin dryer to eliminate water entrapment and facilitate drying (Reference 7).

4. Supplemental Processing

a. Significance

Both the cadmium plating and the IVD aluminum coating processes are limited regarding their ability to coat into bores and deep recesses. But unlike the cadmium plating process, no auxiliary electrodes or coating wands exist to apply the IVD aluminum coating into recesses. The IVD coating process does provide an effective corrosion resistant coating into a depth approximately equal to one times the diameter of the opening. For this application, methods to apply a supplemental coating onto internal surfaces are needed to ensure adequate protection against corrosion.

b. Progress

During the Phase III period, WR applications required virtually no need for supplemental processing. Only one part of the 123 parts changed to IVD aluminum required supplemental processing. A procedure was developed which included an epoxy primer and polysulfide sealant overcoat applied by a fill-and-drain procedure. See Section III. The WR paint shops can apply both sacrificial and barrier-type supplemental coatings by either brush or fill-and-drain methods. If the need for spray applications into long bores arises, supplemental spraying wands will have to be identified and procured.

SECTION III

SUPPORTING DOCUMENTATION NEEDS

A. SUMMARY

Successful implementation of the IVD aluminum process for the various applications at WR that had required cadmium plating requires adequate supporting documentation for plating shop personnel. Documentation needs include authorization to use the coating process, callout of the coating process on the Plating Shop Traveler (Work Order Document), processing requirements after drawing/part review, guidelines for the selection of coating thickness class, identification of any supplemental processing needs, and an up-to-date process specification. During Phase III, MCAIR reviewed current WR documentation, made recommendations, issued coating thickness selection guidelines, and implemented the use of IVD aluminum production procedure cards. This task was completed successfully by close coordination between MCAIR and WR's Material Management, Production, and Industrial/Chemical Process Engineering personnel.

B. TASK

MCAIR coordinated and assisted the WR effort to implement the use of IVD aluminum by the review/initiation of supporting documents such as:

1. Authorization to use
2. Drawings
3. Coating thickness classes
4. Supplemental processing needs
5. Process specification

Successful completion of these activities provides the necessary supporting documentation for full implementation of the IVD aluminum coating process to the shop floor.

1. Authorization to use

a. Significance

Authorization to change from cadmium to IVD aluminum at WR involves approval from the C-130, C-141, and F-15 program offices. Once this approval is given, appropriate changes reflecting the proper use of IVD aluminum in regard to coating class and type are incorporated into the Shop Travelers (Work Control Documents) which accompany parts through the shop area.

b. Progress

o Authorization - The C-130, C-141, the F-15 are the major aircraft overhauled at the WR-ALC. Authorization has been granted to either allow or require the use of IVD aluminum as a replacement for cadmium plating for these programs (References 8 and 9). See Table 3.

TABLE 3. AUTHORIZATION TO USE IVD ALUMINUM COATINGS AS A REPLACEMENT FOR CADMIUM PLATING.

Program	Authorization
C-141	Program Issued Written Approval. TO 1C-141B-3 and TO 141B-23 Revised to Require the Replacement of Cadmium With IVD Aluminum
C-130	Program Issued Written Approval
F-15	Program Issued Verbal Approval Stating the IVD Aluminum Was Already the Process of Choice of MCAIR, the Original Equipment Manufacturer

Processing steps at WR are controlled by a Work Control Document (WCD) which is routed with the part through its maintenance cycle. In the transition to IVD aluminum at WR, some WCDs were changed to reflect IVD aluminum while others still require cadmium plate with blanket approval to change to IVD aluminum.

2. Drawings

a. Significance

A review of the individual drawings/parts is beneficial to assure part processing applicability, establish complete part identification, and specify processing parameters. Part identification and processing parameter information as shown in Table 4 are recorded on Section VI procedure cards. Once parameters are identified and recorded, part processing will remain consistent regardless of the operator and frequency of overhaul.

TABLE 4. PROCESSING PARAMETERS IDENTIFIED DURING DRAWING/PART REVIEW.

Item	Processing Parameters
1	• Cleaning Difficulties/Recommendations
2	• Loading Instructions
3	• Masking Instructions
4	• Coating Class and Type
5	• Vacuum Processing Parameters – Glow Discharge Cleaning Time – Wire Feed Setting – Boat Rack Travel Settings – Number of Coating Passes for Coating Thickness – Number of Convective Cooling Cycles Needed
6	• Part Turnover Required
7	• Procedural Changes Required After Part Turnover

b. Progress

MCAIR conducted a "hands-on" review as parts moved through the maintenance cycle to identify IVD aluminum processing needs throughout the Phase III effort. One hundred and twenty-three configurations that had been plated with cadmium were reviewed for coating thickness class, masking requirements, and possible supplemental processing. All of these configurations are being successfully processed with IVD aluminum. As high usage parts generally cycled through earlier in the period, a maintenance shut-down of the WR cadmium-plate line in February 1992 did not cause concern. The use of the cadmium-plate line has been discontinued since that time on a permanent basis.

3. Coating Thickness Classes

a. Significance

Both cadmium per QQ-P-416 and IVD aluminum per MIL-C-83488 have three coating thickness classes. However, the coating thickness is different between identical classes of the specifications as shown in Table 5.

TABLE 5. MINIMUM COATING/PLATING THICKNESSES.

Coating/Plating Class	Minimum Coating/Plating Thickness (in.)	
	MIL-C-83488	QQ-P-416
1	0.0010	0.0005
2	0.0005	0.0003
3	0.0003	0.0002

The nature of the IVD aluminum coating process allows the coating to be applied thicker than the cadmium plating process. A Class 1 IVD aluminum coating is usually applied to thicknesses of 0.0010-0.0025 inch (MCAIR does not recommend thicknesses above 0.0030 inch because of coating stresses on part edges) while a Class 1 cadmium plating is usually applied to thicknesses of 0.0005-0.0008 inch. Thicker IVD aluminum coatings substantially increase corrosion resistance (Figure 12) and are recommended for general use (i.e., vast majority of non-threaded structural details). However, during transition from cadmium to IVD aluminum, the mind-set is often to apply the same thickness as before, or apply the same class without the realization there is a difference in thickness. The corrosion-resistance benefit from applying thicker IVD aluminum is often not recognized.

b. Progress

WR personnel generally substitute the same class of IVD aluminum coating as that specified for cadmium plating on the Work Control Document.

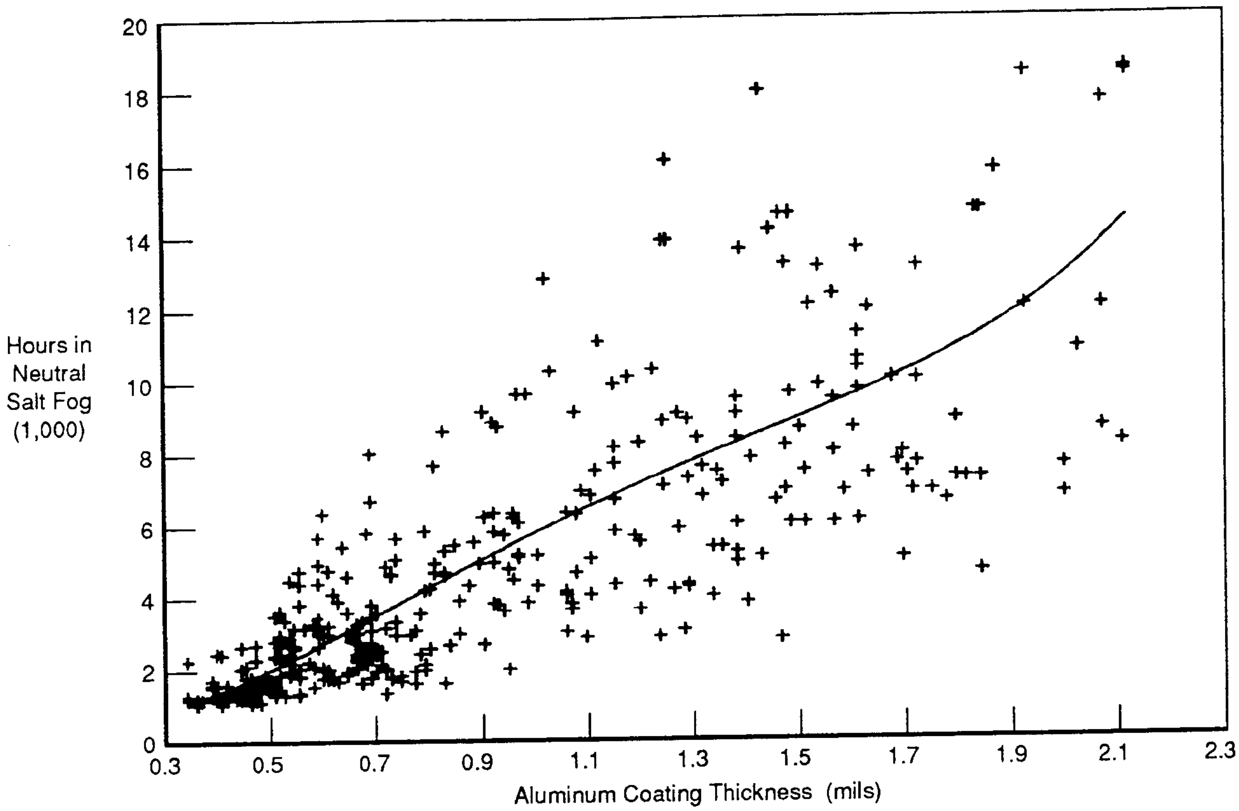


Figure 12. Corrosion Resistance of IVD Aluminum in Neutral Salt Fog.

Initially, however, most operators were unaware of the thickness difference between identical classes of the two finishes. These misunderstandings caused some parts to be processed with a thinner IVD coating then desired for maximum corrosion protection.

MCAIR implemented the Table 6 guidelines shown at WR during Phase III to determine and select appropriate coating thickness for IVD aluminum. In addition, a procedure was implemented to record the applicable coating class/thickness for each part on a Section VI IVD aluminum production procedure card.

TABLE 6. COATING THICKNESS GUIDELINES.

Class	Guidelines
1	Class 1 (0.0010 in. Thick Minimum) Is Recommended for General Use as It Provides the Maximum Corrosion Resistance.
2	Class 2 (0.0005 – 0.0010 in. Thick) Is Recommended Where Class 1 Thickness Is Unacceptable for Dimensional Reasons (Example: Threaded Parts That Are Not Close Tolerance).
3	Class 3 (0.0003 – 0.0005 in. Thick) Is Recommended for Close Tolerance Parts (Example: Class 3A Threaded Parts).

Most nonthreaded WR parts are now coated with 0.0010-0.0025 inch of IVD aluminum. Partially threaded, nonfastener parts are usually coated with either a Class 2 or 3 coating on the threaded area which is then masked and the thickness on the rest of the part increased to Class 1. Fasteners are being coated with a Class 3 coating.

4. Supplemental Processing Needs

a. Significance

The IVD coating process provides a corrosion-resistant coating into a bore or recess for a depth approximately one times the diameter of the opening. Beyond one diameter into the bore, the coating thins and may become non-existent. Supplemental processing is recommended to augment the corrosion resistance of the IVD aluminum coating process for parts containing bores that have length-to-diameter ratios greater than 1:1 (or 2:1 if open on both ends). Research and Development (R&D) conducted during Phase II of this contract revealed that ample corrosion resistance can be obtained by apply a sacrificial- or barrier-type supplemental protection system to thin or non-existent coating on internal part surfaces. The corrosion-resistance requirement for the supplemental protection systems was established at 672 hours in an ASTM B-117 five-percent neutral salt-fog environment which is the same requirement for a Class 1 (0.001 inch minimum), Type II (chromated) IVD aluminum coating. MCAIR actually tested the supplemental protection systems to failure as shown in Table 7. Data in this table have been

TABLE 7. CORROSION RESISTANCE OF SUPPLEMENTAL PROTECTION SYSTEMS APPLIED TO INTERNAL CYLINDER SURFACES IN A FIVE-PERCENT NEUTRAL SALT FOG ENVIRONMENT.

	Alloy Steel Cylinder Internal Surface ASTM-B117 Salt Fog Resistance	
	672 hr	**Duration (hr)**
Processor: Sacraficial Protection System		
MCAIR: Alseal 518	Passed	3,000
MCAIR: Alseal 518, Waterborne Primer, Polyurethane Topcoat	Passed	20,928[b]
Processor: Barrier Type Protection System[a]		
MCAIR: Waterborne Primer, Polysulfide Sealant (Sprayed)	Passed	16,440
MCAIR: Waterborne Primer, Polysulfide Sealant (Brushed)	Passed	13,128
MCAIR: Waterborne Primer, Polysulfide Sealant (Fill and Drain)	Passed	16,872
MCAIR: Epoxy Primer, Polysulfide Sealant, Polyurethane Topcoat	Passed	11,424
Embee Plating: Manganese Phosphate, Epoxy Primer, Polyurethane Topcoat	Passed	21,600[b]
Embee/MCAIR: Manganese Phosphate, Waterborne Primer, High-Solids Polyurethane Topcoat	c	20,280
DeSoto: Epoxy Primer, Epoxy Powder Coating	Passed	21,096[b]
DeSoto: Waterborne Primer, Epoxy Powder Coating	c	10,240

a Although these systems are designated barriers, some component materials contain leachable compounds which provide some chemical protection.

b Cylinders had not failed (red rust) at end of test.

c Topcoat contained several small craters extending to primer coat. Pencil-point areas of red rust in craters observed at 672 hours. Specimens left in test, with no additional degradation until final failure.

updated since the conclusion of Phase II as the test was still in progress. R&D directed at other "areas of concern" expressed by the ALCs for the IVD aluminum replacement of cadmium; namely: torque-tension characteristics and erosion resistance are also addressed in Reference 2.

b. Progress

MCAIR found virtually no need for supplemental processing at WR. Some applications at other ALCs will require more use of supplemental processing.

Supplemental processing was recommended for the C-141 Jack Support Pad, P/N 865891-10. The part has a cylindrical cavity closed at one end. The cavity is 6-inches long and 3 inches in diameter, a length-to-diameter ratio of two. IVD aluminum provides sufficient coverage of cylindrical cavities with length-to-diameter ratios of one if closed at one end and two if open at both ends. MIL-P-23377 epoxy primer overcoated with MIL-S-81733 polysulfide sealant was applied over the IVD coating in the cavity by a fill and drain method. This procedure has been incorporated into the Work Control Document, drawing, and Section VI IVD aluminum production procedure form.

5. Process Specification

a. Significance

The correct execution of most production processes requires current processing information. The WR IVD aluminum process specification provides the coater operator information on needed related documents, equipment, materials, classes and types of coatings, processing procedures, quality assurance requirements, and safety related items. Adherence to current process requirements will help assure continued success of the IVD coating operation at WR.

b. Progress

The WR process specification, Reference 10, was updated on 5 June 1992 by WR personnel: Marti Sedgwick, IVD process engineer; B. J. Adams, Tommy Honeycutt, Jerry Wahl, Edward C. Wright, supervision; and Murry Jackson, principle coater operator; to reflect lessons learned during the joint MCAIR-WR effort to replace cadmium processing with IVD aluminum.

SECTION IV

QUALITY ASSURANCE GUIDELINES

A. SUMMARY

In Phase I of this program, the functional performance of IVD aluminum was compared to that of cadmium with the conclusion that IVD aluminum was an equivalent-to-superior finish. This data was based on IVD aluminum coatings which satisfied the quality and performance requirements of MIL-C-83488, the tri-service IVD aluminum coating military specification. The successful implementation of the IVD aluminum process at WR and other ALCs is also dependent on meeting MIL-SPEC quality and performance requirements. During Phase III, acceptance performance was defined and sufficient testing implemented to verify process control and performance requirements. This effort was completed successfully by close coordination between MCAIR and WR's Production and Industrial/Chemical Processing Engineering personnel.

B. TASK

MCAIR coordinated Quality Assurance guidelines with WR by reviewing/defining such activities as:

1. Acceptance performance requirements/test procedures
2. Test equipment needs
3. Training

Verification of coating performance to MIL-SPEC quality and performance requirements ensures a high quality coating for service applications.

1. Acceptance Performance Requirements/Test Procedures

a. Significance

Meeting the quality and performance requirements of MIL-C-83488 will assure high-quality IVD aluminum coatings for ALC application, as well as enhancing approval and use. To this end, quality/performance requirements need to be defined and appropriate testing implemented to assure mil-spec adherence.

b. Progress

The requirements of MIL-C-83488 were established as the quality and performance baseline for IVD aluminum coating at WR. MIL-C-83488 quality/performance requirements are based on the following: coating appearance, coverage, adhesion, thickness, corrosion resistance, and substrate (part) harness.

o Appearance and Coverage - MIL-C-83488 requires that the coating shall completely cover all visible surfaces including roots of threads, recesses, and sharp corners. It also requires that the coating shall be smooth, fine grained, adherent, uniform in appearance and be free of staining, pits, and other defects. WR implemented routine inspection of all parts for satisfactory coating appearance and complete coating coverage in July 1991.

o Adhesion - Coating adhesion is being tested at WR by both destructive and nondestructive testing. WR conducts 100 percent nondestructive testing on all coated parts supplemented by periodic destructive testing.

- Destructive testing (bend-to-break coupons) was implemented at WR in October 1991. This test is performed on 1- x 4- x 0.040-inch, 4130 alloy steel panels that are cleaned exactly like the production parts and coated with them. Coating adhesion is determined by placing the coupon in a vice and bending it back and forth until the coupon breaks. For this test, MIL-C-83488 requires no separation of the coating from the base metal when examined at 4X magnification.

Nondestructive test procedures were firmly established and implemented in July 1991 to check coating adhesion on all production parts by glass-bead peening. At WR, this test is performed in a large, walk-in glass-bead peener using a 1/2-inch diameter nozzle, number 13 glass beads, and a glass-bead peening pressure of approximately 40 psi. The nozzle is held 6 inches away from the part and slowly fanned over it. The glass beads burnish the aluminum coating as well as apply stresses to the coating at the impingement site. Coating stresses are sufficient to lift off poorly adherent coating yet insufficient to cause any damage to the part or coating. Although ML-C-83488 does not require glass-bead peening, MCAIR believes it is the most effective way to test IVD coating adhesion and recommends its use for all IVD aluminum applications.

o Thickness - MIL-C-83488 requires coating thicknesses per Table 8 on all visible surfaces except in holes, recesses, internal threads and other areas where a controlled deposit cannot be obtained. Thickness checks were implemented at WR in July 1991 with an instrument provided by MCAIR until WR procured their own state-of-the-art instrument. Guidelines for determining the test article depending on part material were also implemented:

- Alloy Steel - Measure the thickness of the aluminum coating directly on the production parts.

- Aluminum Alloy - Measure the thickness on 1 x 4 inch steel companion coupons

TABLE 8. COATING THICKNESS REQUIREMENTS.

Coating Class	Coating Thickness (in.)
1	0.0010 Minimum
2	0.0005 Minimum
3	0.0003 Minimum

MCAIR implemented the use of 1 x 4 inch steel companion coupons to determine coating thickness on aluminum-alloy parts. The thickness of the aluminum coating is measured directly on steel parts but cannot be measured on aluminum-alloy parts. A procedure to hang the companion coupons horizontally and at the same distance from the boats as the production parts is in use.

MCAIR has determined that the coating thickness on the relatively small steel coupon must be at least 1.6 times the desired coating thickness class. (Example: To assure a Class 1 (0.001 inch thick minimum) coating on an aluminum alloy part, the coating thickness on the coupon must be at least 0.0016 inch thick.) This correlation is defined in MCAIR's process specification and was verified for the WR coater.

o Corrosion Resistance - MIL-C-83488 requires that test specimens show no evidence of corrosion to the base metal when exposed to a ASTM B-117 neutral salt-fog environment per the test duration listed in Table 9. Testing was fully implemented at WR in October 1991. This test is performed on 4 x 6 x 0.050 inch, 4130 alloy-steel panels. Two Type II (chromated) panels are processed and are tested on a monthly basis for each coating thickness class.

TABLE 9. CORROSION RESISTANCE REQUIREMENTS FOR IVD ALUMINUM COATED PARTS IN FIVE-PERCENT NEUTRAL SALT FOG.

Coating Class	Coating Thickness (in.)	Test Duration (hr)
1	0.0010 minimum	672
2	0.0005 minimum	504
3	0.0003 minimum	336

The corrosion resistance is satisfactory if no corrosion (red rust) of the steel occurs during the test duration for each respective coating class. The appearance of white corrosion products on the coating is not cause for rejection. All WR processed test panels have met the mil-spec requirement for corrosion resistance from implementation in October 1991 through June 1992.

o Substrate (Part) Hardness - MIL-C-83488 requires that the coating shall not cause any degradation of the base metal. MCAIR recommends that the hardness of the aluminum-alloy parts be verified after coating. The condensation of the aluminum vapor on the production part during coating causes a temperature rise in the part. Since the tempering temperature for alloy-steel parts is relatively high, the heating effect caused by the coating is of little concern. However, the temperature for aluminum-alloy parts is relatively low. Therefore, procedures for processing temperature sensitive aluminum-alloy parts need adjustment to prevent overheating. Hardness testing of aluminum alloys was implemented at WR in August 1992. They use a "Rockwell"-type stationary hardness tester to document process temperature control (no part overheating).

2. Test Equipment Needs

a. Significance

Adequate equipment to test coatings properties such as adhesion, thickness, corrosion resistance, and part hardness are essential for compliance to quality and performance requirements. Glass-bead peening equipment, hardness test machines, coating thickness measuring devices, and salt-fog cabinets need proper maintenance and/or calibration to ensure accurate results. Hardness test equipment accuracy is especially important to preclude undetected overheating of parts. Thickness measurement accuracy is important to verify that the desired amount of coating has been applied for optimum corrosion performance or part tolerance control. Thickness measurement accuracy may be compromised without proper instrument calibration as many ALC parts have relatively rough surfaces.

b. Progress

o The glass-bead peening procedure and equipment are discussed in Section II.

o Coating Thickness Measuring Instrumentation - MCAIR found the initial thickness measuring instruments at WR to be inadequate for measuring IVD aluminum coating on steel. MCAIR provided instrumentation until WR procured their own instrumentation, an Elektro-Physik USA Minitest 4000 with F-1 and N-1 probes, in December 1991.

The Minitest 4000 is a small, digital instrument capable of measuring the thickness of most nonmagnetic coatings applied to steel parts with the F-1 probe. The instrument has extensive data recording capability and statistical evaluation of that data. In addition, the instrument allows multi-calibrations to be established and retained for future recall for different steel-alloy compositions.

Both surface roughness and steel-alloy composition affect thickness measurements. Many ALC parts exhibit rougher surface finishes than new parts due to field use and multiple maintenance cycles. Also the number of aircraft programs at a facility like WR assures activity with several different alloy-steel compositions. As a result, MCAIR provided extension training to WR personnel in the areas of instrument calibration. The effect of surface roughness and steel-alloy composition on measurement accuracy was also evaluated.

A two-point calibration procedure is recommended prior to making thickness measurements. For the WR instrumentation, a bare surface and a 0.002 inch thick plastic shim are used for the calibration. When the F1 probe is placed on a smooth steel surface, an initial thickness measurement is obtained. A zero calibration electronically accepts this value. With a smooth surface, successive measurements produce a zero thickness or very slight +/- thickness differences. Surface roughness affects the zero calibration point the most. As the surface roughness increases from smooth to 20 mesh, the magnitude of the +/- variations in the zero measurements above the initial value increases. The effect of surface roughness is less pronounced with the use of the 0.002 inch thick plastic shim. The effect of surface roughness on both calibrations is minimized by taking several measurements at each calibration point, a minimum of five. Electronically the multi-measurements at each calibration point are averaged, producing an optimum calibration of the zero and of the 0.002 inch points on the rough surface.

Steel-alloy composition affects the zero calibration point more than the 0.002 inch calibration point. The steel-alloy compositional variation apparently changes the magnetic characteristics of the material. To achieve the highest accuracy coating thickness measurements, a two-point calibration is recommended for each steel alloy.

In conclusion, the effect caused by surface roughness/steel alloy on Class 1 coatings (majority of use) is minimal with proper instrument calibration.

Prior to receiving their Minitest 4000 unit, WR used a MCAIR Dualscope, model DSS-T3A/GB2A, to measure aluminum-coating thickness. The

Dualscope also uses a two-point calibration. A bare spot on the steel substrate is used to establish the gauge zero coating thickness, and an aluminum-foil shim, either 0.9 mil (0.0009 inch) or 1.8 mils (0.0018 inch) thick, is used for the upper-calibration point.

The accuracy of the Minitest 4000 was compared to the Dualscope, and the effect of calibration foil thickness on the coating thickness accuracy and measurement repeatability was investigated.

Calibrations were performed using the aluminum-foil shims and a 2.0 mil (0.002 inch) thick plastic shim provided with the Minitest 4000.

Calibration of the Minitest 4000 with either plastic or aluminum-foil shims produced almost identical results, Table 10. Although the Minitest

TABLE 10. EFFECT OF THICKNESS AND TYPE OF CALIBRATION SHIM ON THE ACCURACY AND REPEATABILITY OF THICKNESS MEASUREMENTS FOR THE MINITEST 4000.

IVD Aluminum Coating Thickness for Calibration Based on Different Shim Thicknesses			Thickness of Calibration Shim on Bare Substrate for Calibrations Based on Different Shim Thicknesses		Remarks
1.97 (mil)	1.80 (mil)	0.90 (mil)	1.80 (mil)	0.90 (mil)	
1.66	1.64				1.97 mil Shim Is Plastic.
1.72	1.67				
1.07	1.09				
	1.03 }	1.10			1.80 and 0.90 mil Shims Are Aluminum Foil.
	1.05 }				
	0.92 }	0.96			
	0.96 }				
		0.66 }			
		0.71 }			
		0.73 }			
		0.72 }			
			1.83		Calibration Shim Thickness of 1.8 mil.
				0.50	Calibration Shim Thickness of 0.54 mil.

} Repeatability – Measurement of IVD aluminum coating thickness for different calibration setups on the same part.

4000 should be calibrated using shims of the approximate thickness of the coatings being measured, measurement errors were less than eight percent even when the coating thickness was only 60 percent of the calibration shim thickness.

Figure 13 compares coating thickness measurements made with the Minitest 4000 and the Dualscope on steel-alloy strips. Measurements by the two instruments tracked closely, within five percent of each other for coatings 0.0003 to 0.0020 inch thick. The digital Minitest 4000 is superior to the analog Dualscope in readability. Also the Minitest 4000 can easily average multi-measurements of the coating thickness at any measurement site. The Dualscope does not have this statistical capability.

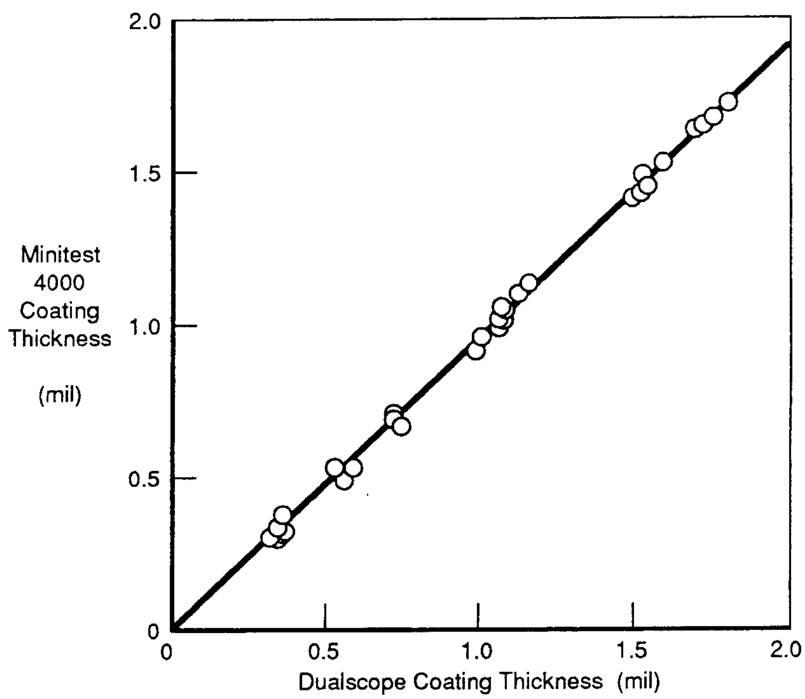


Figure 13. Comparison of IVD Aluminum Coating Thickness Measurements Using Minitest 4000 and Dualscope.

3. Training

a. Significance

Trained personnel are required to ascertain coating properties to the quality and performance requirements of MIL-C-83488. Quality Assurance training covers: acceptance criteria; test equipment needs, calibration, and use; and test procedure implementation. Properly trained IVD coating operators/inspectors recognize coating problems and can implement the necessary corrective action to identify problem source and solution.

b. Progress

o Hardness Measurements - The hardness of aluminum-alloy parts at WR is measured with a "Rockwell" type stationary hardness tester to document process temperature control (no part overheating). Prior to Phase III, hardness measurements of IVD aluminum-coated parts were made by the WR laboratory. To improve efficiency, hardness measurement testing was relocated to the IVD aluminum-coating area. MCAIR assisted this effort by training WR production personnel. Training was directed at topics shown in Table 11.

TABLE 11. HARDNESS TRAINING TOPICS.

Item	Training Topic
1	Familiarization With Procedures Used by MCAIR to Test F-15 Aluminum Alloy Parts
2	Familiarization With the Hardness Testers
3	Setup and Leveling of Support Stand/Parts
4	Verification of Hardness Measurement Accuracy
5	Measurement Techniques

During November 1991, WR experienced a problem in which the hardness tester could not be zeroed per standard operating instructions. The instrument probably received a severe jar, deflecting a small needle on the instrument. The manufacturer recommended a variation in standard operating instructions that allowed the hardness tester to be successfully zeroed. WR personnel were taught the new procedure.

o Coating Thickness Measurements - WR purchased an Elektro Physik USA Minitest 4000. The Minitest 4000 is a small, digital instrument capable of measuring the thickness of IVD aluminum coatings on steel-alloy parts. WR personnel were trained on its use. Training topics are shown in Table 12.

TABLE 12. MINITEST 4000 TRAINING TOPICS.

Item	Training Topic
1	Basic Familiarization With the Instrument
2	One-Point Calibration
3	Two-Point Calibration
4	Measurement Procedure
5	Statistical Evaluation of the Data

o Other training - Training was provided throughout the Phase III period on both a periodic basis and as problems arose in the areas of coater operation, coater accessories, equipment problems and solutions, and quality assurance testing.

SECTION V

ENVIRONMENTAL COMPLIANCE

A. SUMMARY

The Phase III demonstration/implementation of the IVD aluminum process at WR has been an across-the-board replacement for cadmium processing. Elimination of cadmium processing at WR reduces hazardous waste production arising from both the cadmium metal and cadmium-plating baths. Cadmium is a heavy metal and is toxic to humans. Once it escapes into the environment, it can find its way into the water supply or food chain. Electroplated cadmium processing produces additional hazards associated with cyanide products in the plating bath. Both IVD aluminum and the IVD aluminum process are safe for the environment and for the personnel performing the process.

B. TASK

MCAIR verified environmental compliance progress associated with the elimination of cadmium processing with WR Environmental Management and presented MCAIR activities directed at environmental compliance.

1. Environmental Compliance of Phase III Processing

a. Significance

The functional merits of IVD aluminum versus cadmium processing have been thoroughly discussed in Reference 1. The most important reason for replacing cadmium with IVD aluminum at the ALCs may be found, however, in an examination of how the two metals and their respective processing procedures impact the environment.

Both aluminum and cadmium as metallic finishes require a similar processing sequence of precleaning, coating or plating, and postcoat processing. Because most of the precleaning and postcoat processing steps are common to both finishes, it is the nature of the two metals and the actual plating or coating process that exhibits most of their environmental impact differences. Aluminum is an environmentally compliant substance, and the IVD vacuum-coating process is a dry, environmentally clean process. Cadmium, on the other hand, is classified as toxic to humans and widely regarded as a suspect human carcinogen; waste cadmium must be handled and disposed of by approved Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA) procedures. In addition, electroplated-cadmium processing introduces additional hazardous waste materials, such as cyanide in the plating bath, which must be controlled. Cyanides are also extremely toxic and present unique hazards to personnel.

b. Progress

o Precleaning - The IVD aluminum and the various cadmium processes require part precleaning prior to application of the finish. These part precleaning processes for alloy-steel parts are shown in Table 13.

TABLE 13. PRECLEANING REQUIREMENTS.

Process	Solvents	Chemicals	Others
IVD Aluminum	Alcohol Acetone MEK Chlorinated Solvents[a]	None	Abrasive (Al_2O_3 & Air)
Vacuum Cadmium	Alcohol Acetone MEK Chlorinated Solvents[a]	None	Abrasive (Al_2O_3 & Air)
Electroplated Cadmium Nickel-Cadmium	Alcohol Acetone MEK Chlorinated Solvents[a]	Sodium Cyanide (Option) Sodium Hydroxide Hydrochloric Acid (20°Be)	None
Low-Embrittlement Cadmium	Alcohol Acetone MEK Chlorinated Solvents[a]	None	Abrasive (Al_2O_3 & Air)

a 1, 1, 1 Trichloroethane, Trichloroethylene, Perchloroethylene

Precleaning at WR for IVD aluminum consists of:

- Vapor degreasing to remove organic contaminants from the part surface such as grease and oil films, cutting fluids, and corrosion prevention compounds.

- Mechanical cleaning to remove surface oxides.

Vapor degreasing is the most common solvent-cleaning process. It is now used by WR for IVD aluminum and was used for cadmium processing. Vapor degreasers use a chlorinated solvent as the cleaning agent. Various regulatory agencies have determined that chlorinated solvents contribute varying degrees of harm to a worker's health and the environment. Under the 1990 Clean Air Act Amendment (CAAA), the EPA issued new air toxics control regulations which will specifically address vapor degreasing. Federal air toxics rules for vapor degreasing are expected to be issued by February 1994 with existing degreasers having a maximum of 3 years to comply. WR uses 1,1,1 trichloroethane (TCA) which is also an Ozone-Layer-Depleting Substance (OLDS). Initiatives being set by the Bush Administration and the Air Force addressing OLDS will more than likely force an earlier replacement of TCA. OLDS producers are being asked to end production by 1995 and a ban on its usage is being considered by the Air Force as early as October 1993. The use of another chlorinated solvent such as trichloroethylene (TCE) may extend the period before there is a forced change to another cleaning procedure. However, TCE presents a volatile organic compound (VOC) problem as well as the CAAA problem. MCAIR is evaluating aqueous degreasing, furnace drying, and grit blasting as a replacement for degreasing with chlorinated solvents.

For the application of IVD aluminum, alloy steel parts must be mechanically cleaned after solvent cleaning. Surface oxides are abrasively removed at WR by a process that requires clean, dry air and aluminum oxide or sand grit. This dry process is nontoxic and has no environmental impact when performed with properly maintained equipment.

o Coating/Plating - The application of low toxicity IVD aluminum onto a part surface does not require any outside chemicals or compounds, and there is no waste disposal requirement. The process utilizes an environmentally clean vacuum evaporation to apply the coating. Figure 14 shows the stationary parts-hanging rack being positioned in place in the WR coater. Figure 15 shows the closed coater and the WR operator at the control console in the environmentally friendly work area.

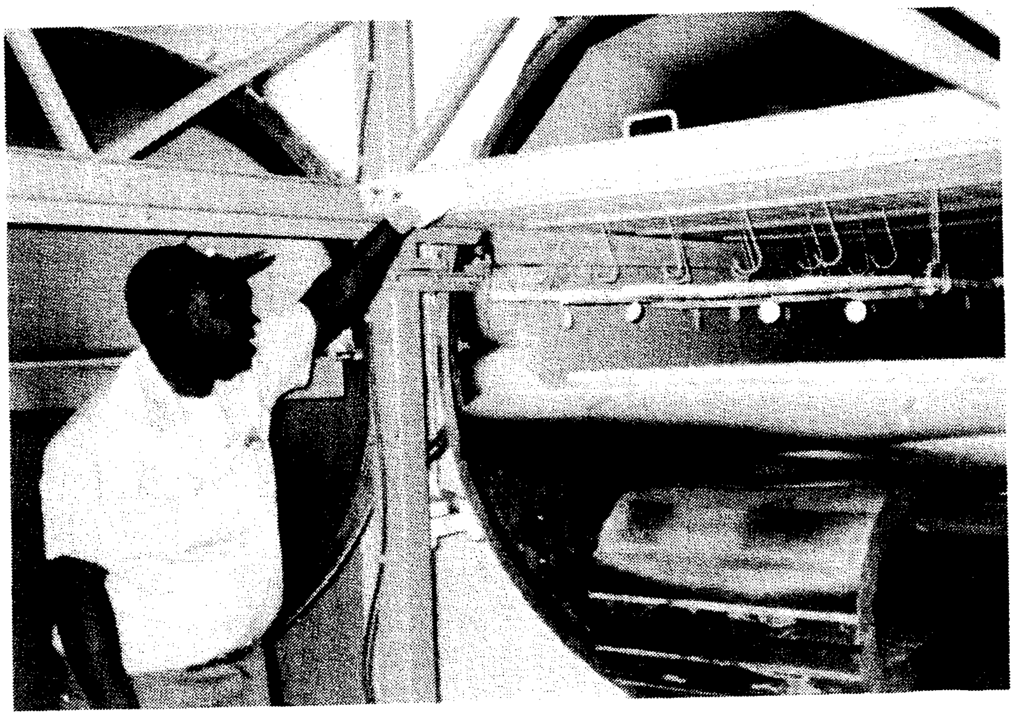


Figure 14. Installation of Stationary Rack Into Warner Robins IVD Aluminum Coater.

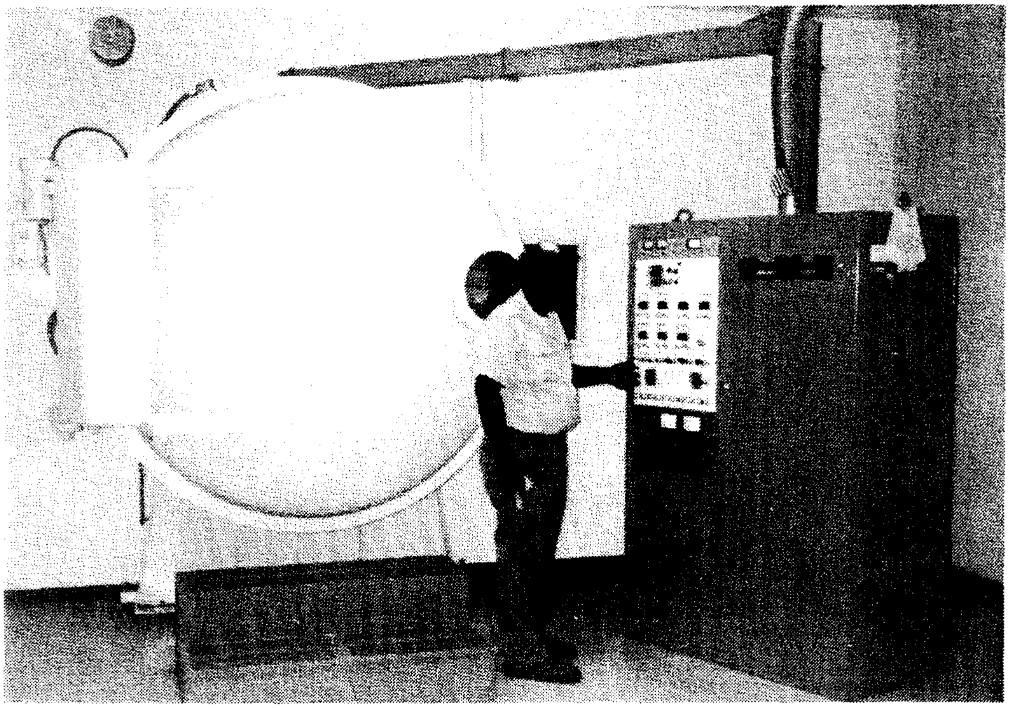


Figure 15. Operation of Warner Robins IVD Aluminum Coater.

Waste disposal is a major problem for the cadmium processes. Treatment of cadmium plating solutions and rinsewaters is required. This is usually a two-step process requiring the destruction of cyanide followed by precipitation of the cadmium. Both steps require separate tanks, instrumentation, chemicals, and man-hours. The cyanide destruction is generally performed by the alkaline chlorination-oxidation process. This process is a two-stage operation in which the cyanide is first converted to a cyanate and then the cyanate is oxidized to carbon dioxide (usually as sodium bicarbonate) and nitrogen. Sodium hydroxide is used with a chlorine source to maintain the pH of the solution at the proper levels for the oxidation reactions to occur.

The effluent from these processes can be diluted or buffered to produce wastewater which meets pretreatment standards after the filtration of the precipitated cadmium compound. This remaining hazardous sludge must be dried, stabilized, and disposed of in a hazardous waste disposal site. Even then, the environmental problems have not ended. Cadmium can be extremely hazardous if it gets into the ground water system; the allowable concentration in waste water is only one-fifth that for arsenic. As a result of these problems and the associated liability, disposal costs are high and are continuing to rise. Federal treatment standards for land disposal of cadmium-bearing sludge are stringent, and are subject to future modification.

o POSTCOAT PROCESSING - The postcoat processing steps for both IVD aluminum and the various cadmium processes are essentially the same. Both use a chromate conversion treatment which provides additional corrosion protection and a base for subsequent paint adhesion. WR uses Alumigold which is an acceptable MIL-C-5541, Class 1A treatment for IVD aluminum coating. The use of chromates is under scrutiny by regulatory agencies because of the possibility that upper respiratory cancer may be caused by hexavalent chrome and water pollution from chrome in any form. The main occupational health concern with the chrome compounds is with inhalation of dust, powders, or liquid mist, and the corrosive effects on the skin and the mucous membranes of the upper respiratory tract.

Pending environmental regulations will further restrict chromium usage. A waste-water-pretreatment rule expected to become effective in 1995 will lower chromium-discharge limits. The 1990 CAAA will set limits for chromium air emissions. Chromate conversion coatings are expected to fall within the Aerospace Air Toxics Rule. Limits are expected to be set by November 1994 with industry having a maximum of 3 years to comply. As a result of existing and pending regulations, most airframers plan to replace processes containing chrome compounds as environmentally acceptable replacement materials and processes evolve from research and development (R&D) laboratories.

The chromate conversion process can be a closed-loop system which limits the amount of waste products. However, MCAIR recommends replacement of chromate conversion coatings for IVD aluminum with non-chromated conversion coatings. Further R&D is recommended to find a replacement conversion coating that is environmentally acceptable and has no detrimental effect on the current effectiveness of the coating.

o Occupational Safety and Health Act (OSHA) STANDARDS - Cadmium processors must comply with OSHA Standards as well as EPA regulations. Inhaling small quantities of cadmium dust or fumes may cause a dry throat, cough, chest pain, headache, shortness of breath, and vomiting. More severe exposure could result in death. OSHA is in the process of developing a standard for the levels and monitoring of cadmium in the work place. OSHA has proposed a personal exposure limit (PEL) of 5 micrograms of cadmium per cubic meter as an average over 8 hours. An airborne concentration as low as 1 microgram per cubic meter as an average, over 8 hours, is proposed as an action level. Medical surveillance would be required for all exposures at or above action levels. Warning signs and step-by-step training would be required. Initial representative monitoring would be performed on every full-shift employee in each job classification and work area within 120 days. Regulated areas would be established for concentrations above the PEL. Processors would be required to have a written plan to deal with emergencies including a change room with showers for exposures above the PEL. Private industry and ALCs alike will be required to meet these stringent regulations which will add cost to cadmium processing. The use of cyanide solutions in the cadmium plating process also has an impact on the safety in the work area. As previously outlined, a toxic gas would be generated if an acid was inadvertently added to a cyanide solution. The present OSHA standard has a threshold limit value (TLV) of 5 mg/M^3 in air, and the Department of Transportation requires labelling to state "Poison A, Poison Gas and Flammable" on all shipments of cyanide concentrate.

Conversely, aluminum has low toxicity and is safe to handle, store, and dispose of with standard shop practices. From the toxicity standpoint, aluminum dust or powder is regulated only at the "nuisance dust" level by OSHA.

o Air Sampling Measurements - During September 1991, the WR Bioenvironmental Engineering Services conducted an air sampling program in the IVD aluminum coating area to measure the quantity, if any, of aluminum dust or fumes generated by the IVD coating process. During November 1991, they reported insignificant levels of detection. These results verify the hypothesis that aluminum fumes should not exist since the aluminum vapor condenses upon the parts or shields within the coater. The most likely time for aluminum dust, if any, to be introduced into the coating area is when the coater is opened at the completion of a coating cycle or during the removal of the stainless-steel-coater shields from the coater for cleaning. Personnel and area monitors were used to sample air for aluminum content during a coating cycle and during the complete change of the stainless-steel shields.

All personnel and ambient air sample measurements within the closed IVD coating area were at or below the detection limit of the measuring equipment. The aluminum-fume concentration was basically nonexistent being less than 1/250th of the exposure standard. The maximum dust concentration was also low being less than 1/500th of the exposure standard. See Table 14.

TABLE 14. ALUMINUM CONCENTRATION IN IVD COATING AREA.

Procedure	Aluminum Concentration	
	Measured (mg/m^3)	Exposure Standard (mg/m^3) [a]
During IVD Process/ Part Removal	0.02[b]	5.0
During Shield Change	0.02	10.0

a. No known health problems occur for an individual exposed to this aluminum concentration for 8 hours/day, 40 hours/week. The exposure standard differs based on the form in which the aluminum occurs during different phases of the IVD process, fumes 5.0 and dust 10 mg/m^3, respectively.
b. Signifies none detected and the detection limit.

Based on these measurements, the Bioenvironmental Engineering Services reported "no inhalation hazards existed at the time of the survey." There have been no fume/dust related problems associated with the IVD aluminum process reported to MCAIR during the 17 years of its production use.

o PAINT STRIPPING - Cadmium and aluminum are both soft metals and as such may mix with solutions or blast media used to strip paint from finished parts. The environmental difference once again is in the nature of the metals.

The cadmium-contaminated stripping solution or blast media is required to be disposed of as hazardous waste. Proposed OSHA PELs for cadmium, previously discussed, may well limit the effectiveness of the newer blast media paint stripping procedures. Unacceptable limits of cadmium have been found in the blast media at the Ogden ALC. The source of the cadmium is primarily from cadmium-plated alloy-steel fasteners installed in aluminum-alloy structure and cadmium-plated detail parts such as landing gear components. The replacement of cadmium with IVD aluminum will eventually eliminate this environmental waste stream.

In summary, the use of IVD aluminum to replace the various cadmium processes is an acceptable way to improve the product while eliminating environmental problems associated with the use of cadmium without introducing new ones.

2. MCAIR's Environmental Compliance Overview

a. Significance

MCAIR, as well as most other aircraft manufacturers are developing/implementing environmentally acceptable materials and processes to replace those that are hazardous to the worker, produce hazardous waste, deplete the upper ozone layer, produce air toxins, or emit VOCs. New environmental regulations are continuously coming on-line while existing regulations are continuously ratcheting to tighter, more stringent control levels making collection, storage, and disposal of waste products more and more expensive.

Because of the enormity of developing/implementing compliant materials and processes for the vast number of hazardous materials currently used in the manufacture of military aircraft, manufacturers have sometimes joined to address common problems. The Aerospace Chromium Elimination Team has members from various aerospace companies investigating replacement materials and processes for those containing chromium compounds. Since many chromium containing materials have been identified as carcinogenic, they are identified for eventual elimination or, if used, emissions will be stringently controlled. MCAIR is a member of the Chromium Elimination Team and is the project focal point for sealants, chemical milling, and fuel tank coatings. In addition, MCAIR is a project committee member on five other chromium elimination teams working on other chromium containing materials and processes. The environmental compliance problems facing the aircraft industry today are also common to DoD overhaul facilities such as WR. An overview of MCAIR's environmental activity should benefit the Environmental Management activity at WR.

b. Progress

o MCAIR's Environmental Compliance Overview - During February 1992, Mr. Sheldon Toepke, Unit Chief in MCAIR's Environmentally Compliant Materials and Process Strategic Technology Group, presented MCAIR's environmental compliance program, the Aerospace Chrome Elimination Team activities, new/impending environmental laws, and implementation impact of the new/impending environmental laws at the ALCs to WR, (Reference 11). The WR personnel concerned about the potential impact of the 1990 CAAA on the WR facility requested Mr. Toepke represent his CAAA material and potential cost impact to an expanded group of WR upper management and Environmental Management personnel. This was accomplished in May 1992.

SECTION VI

MANUFACTURING DEMONSTRATION

A. SUMMARY

The full implementation of IVD aluminum at WR or any other ALC along with the corresponding discontinuation of their cadmium plating facility is dependent primarily on two factors. The first factor is the demonstration of the applicability of the IVD aluminum process for a particular ALC by processing each and every part that is cycled through their maintenance activity. The second factor is the verification that the applied coating meets all of the performance requirements of the IVD aluminum military specification. Conformance to these requirements produce coatings that meet or exceed the functional performance of cadmium as delineated in Phase I of this program (Reference 1). During Phase III, MCAIR assisted a successful WR effort that processed all parts with IVD aluminum that had been cadmium plated. This effort enabled shutdown of the WR cadmium-plate facility. The use of production procedure cards was implemented to ensure common processing of individual parts regardless of coater operator and maintenance schedules. Section IV inspection testing was implemented to ensure conformance to the IVD aluminum mil-spec. Productivity gains were realized when using state-of-the-art IVD coater equipment/accessories in relation to cadmium when processing C-130 propeller barrel halves. This task was completed successfully by close coordination between MCAIR and the WR's Production personnel.

B. TASK

MCAIR conducted a program with Manufacturing at WR over a 12-month period of time which demonstrated the feasibility of applying IVD aluminum to all parts that had been processed with cadmium. This effort included the following activities:

1. Implementation of Production Procedure Cards

2. State-of-the-art Demonstration Run

3. Verification of Coating Conformance

4. C-130 Barrel Hub Productivity Gains

5. Operator/Maintenance Personnel Training

1. Implementation of Production Procedure Cards

a. Significance

Establishment of detailed processing procedures for each production part enables them to be processed identically regardless of operator and frequency of overhaul. Since IVD aluminum is applied in a vacuum system, quality coatings are most readily obtained from a controlled process. Control of the IVD aluminum coating process is achieved by setting equipment and processing parameters. Automatic control of the equipment by a process controller removes human error and personnel variations from coating operation. Further control is obtained with a detailed written procedure delineating requirements for specialized cleaning, fixturing techniques, part orientation and spacing, coating parameters, and inspection of the finished product. These procedural requirements are recommended to be on a simple, readily available form for use by the IVD coating operator.

b. Progress

MCAIR implemented the use of an IVD aluminum production procedure form (or card) at WR early in the Phase III period. The production procedure card lists a part by number, name, aircraft program, material composition, and required coating thickness and type. The procedure card also lists those equipment/operational parameters shown in Table 15.

A comment section allows additional information needed for that specific part such as detailed masking or fixturing instructions. Figure 16 is an example of a completed production procedure card. Procedure cards were prepared for each part coated at WR during Phase III.

To enable common production procedure card entries for each of the two WR coaters, the voltages to the boat rack and wire feed controllers were adjusted early in Phase III to produce similar rack speeds and wire-feed rates in both coaters. These equipment settings were later fine-tuned to produce identical rack speeds and wire-feed rates for better coating thickness control.

Production procedure cards were prepared for each of the 123 different parts processed with IVD aluminum during Phase III. Adherence to established procedures will enable consistent part processing regardless of operator/schedule. MCAIR recommends this approach to all of the ALCs for coating integrity control.

TABLE 15. IVD ALUMINUM PRODUCTION PROCEDURE CARD ENTRIES.

Procedure Card Item	Equipment/Operational Parameters
• Glow Discharge Time	Time to Glow Discharge Clean Part Prior to Coating
• Wire Feed Setting	Sets the Wire Feed Rate Into the Evaporator
• Boat Rack Setting	Sets the Speed of the Boat Rack
• Number of Coating Passes	Together With the Boat Rack Setting Defines the Total Coating Time
• Number of Cool Downs	Used When Processing Aluminum Alloy Parts to Prevent Overheating
• Part Turnover Required	Yes Means That Both Sides of the Part Must Be Coated to Provide Acceptable Coating Uniformity
• Procedure After Turnover	Denotes Any Parameter Changes After Turnover

<table>
<tr><td colspan="2">PART NUMBER
72-SKA-B-77C</td><td colspan="4">PART NAME
Wing Attach Fitting</td><td>PROGRAM
C-141</td></tr>
<tr><td>MATERIAL
Steel</td><td>GLOW DISCHARGE TIME
15 min</td><td colspan="2">COATING
CLASS: 1
TYPE: II</td><td colspan="2">WIRE FEED SETTING
50%</td><td>BOAT RACK SETTING
10, 5, 5, 10</td></tr>
<tr><td colspan="2">NUMBER OF COATING PASSES
8</td><td>NUMBER OF COOL DOWNS
1*
(Optional)</td><td colspan="2">PART TURNOVER REQUIRED
Yes</td><td colspan="2">PROCEDURE AFTER TURNOVER
Same</td></tr>
<tr><td colspan="7">MASK INSTRUCTIONS:
None</td></tr>
<tr><td colspan="7">LOAD INSTRUCTIONS:
Hang parts horizontally using 8 in. or 10 in. hooks. For first side coated, hang parts with cavity toward boats.</td></tr>
<tr><td colspan="7">COMMENTS:
Boat rack travel from front to rear of chamber and return equals two coating passes.</td></tr>
</table>

*Cool parts after coating for ease of removal from parts rack, if desired.

Figure 16. IVD Aluminum Production Procedure Card.

2. State-of-the-art Demonstration Runs

a. Significance

Demonstration runs verify the feasibility of the IVD aluminum process for a specific part and the appropriateness of the developed coating procedure for that part. From experience, coating feasibility and procedural development can be determined by visual review for most parts/drawings. However, parts requiring extensive fixturing or masking, parts with deep recesses, and parts with special tolerances may need one or more demonstration runs to determine optimum coating requirements.

b. Progress

During Phase III, processing data delineated on production procedure cards was routinely verified for each new part cycled through the IVD coating area. While most WR parts, such as those shown in Figures 17 and 18, required little-to-no special consideration, others required specialized cleaning, fixturing, or part orientation.

o C-141 Bellcrank Assembly Parts - Reusable fixtures, discussed in Section II, were used successfully to mask selective areas of socket retainer halves (9, 10) and the ball joint shaft (11) of the C-141 Main Landing Gear Bellcrank Assembly, (Figures 4 and 5). This demonstration verified that a high level of productivity can be maintained even for applications requiring extensive masking with proper fixturing.

o The C-130 Propeller Assembly contains two details that were identified as challenging for the IVD aluminum process during Phase I of this program. The propeller hub, Item 28 in Figure 19, is composed of two barrel halves, front and rear, shown in greater detail as Items 28 and 29 in Figure 20. The front half (Item 28), although large, is fixtured to the stationary part rack. No masking of the front half is required. The rear barrel half (Item 29) is large, heavy, and requires extensive masking of chrome-plated areas and other

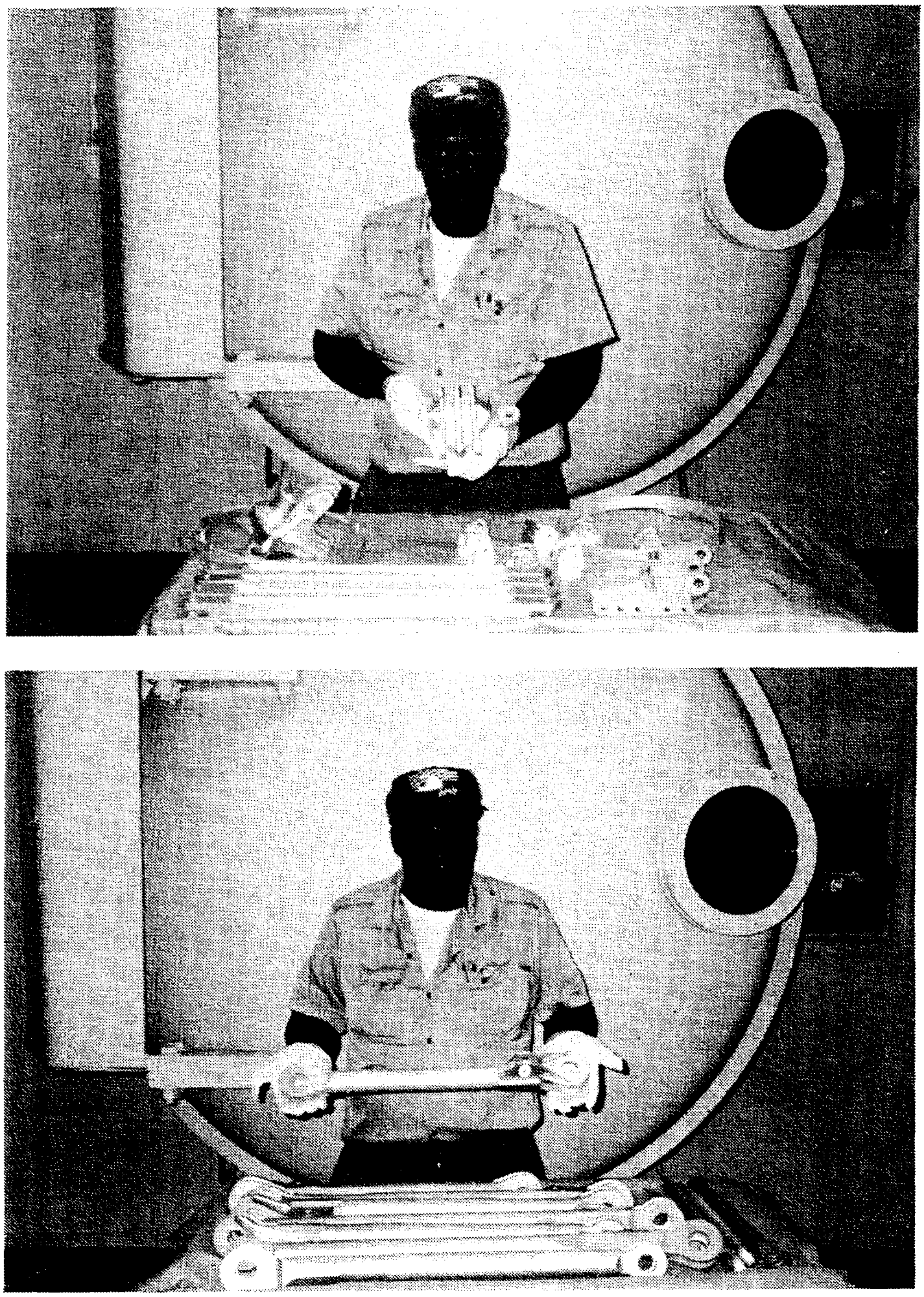


Figure 17. Typically Processed Warner Robins Steel Parts After IVD Aluminum and Glass-Bead Peening.

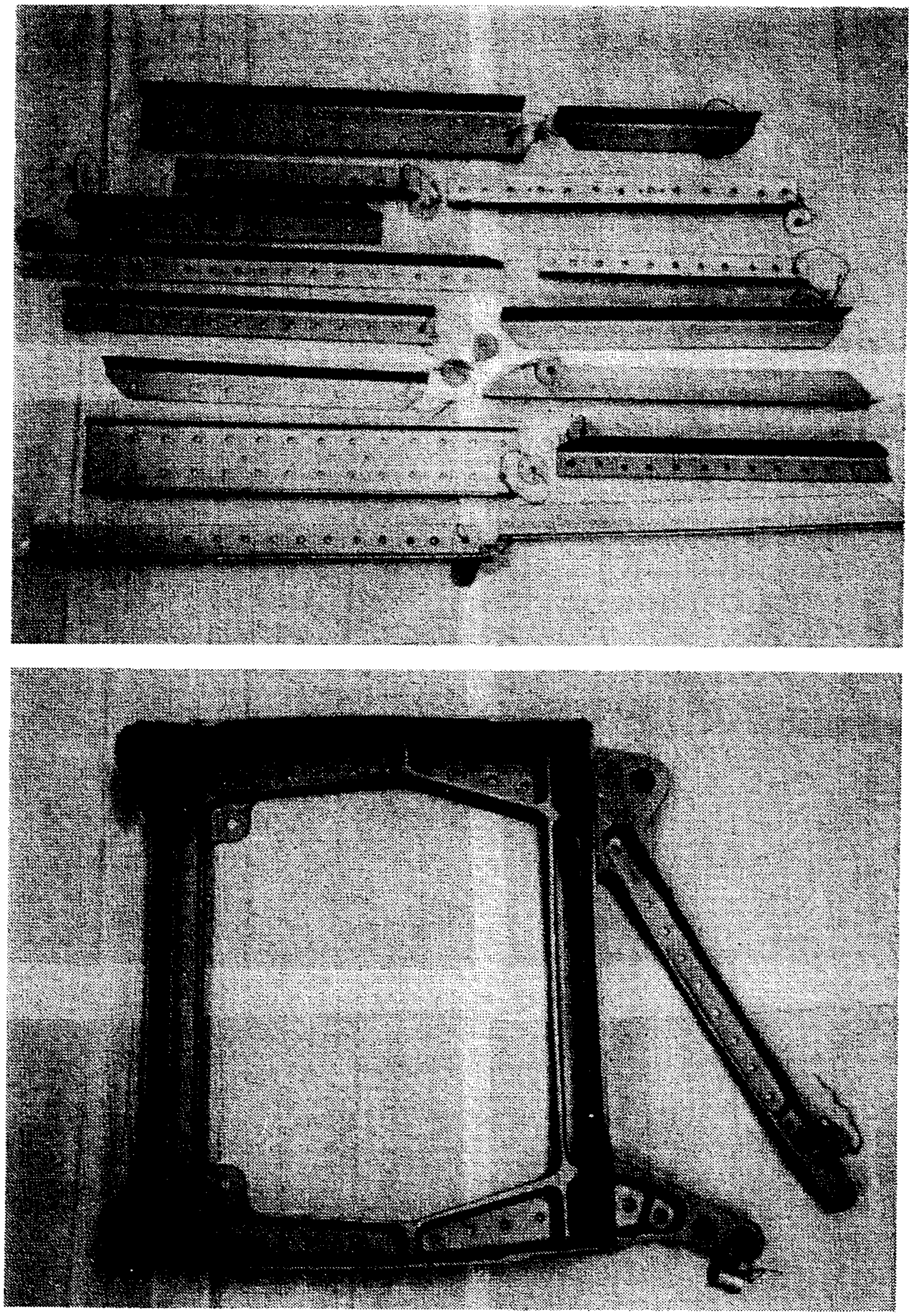


Figure 18. Typically Processed Warner Robins Steel Parts After IVD Aluminum, Glass-Bead Peening, and Chemical Conversion Coating.

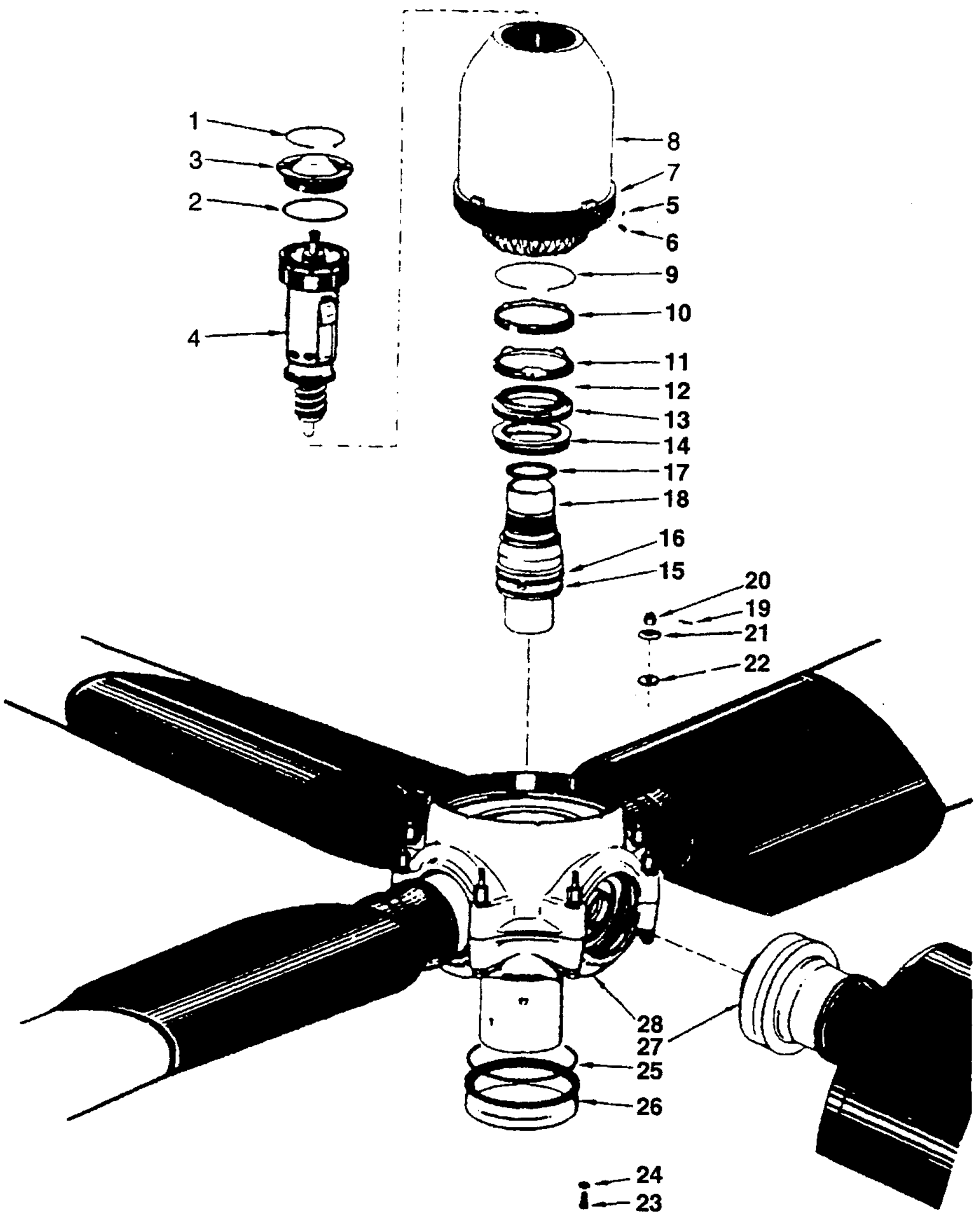


Figure 19. Variable-Pitch Aircraft Propeller.

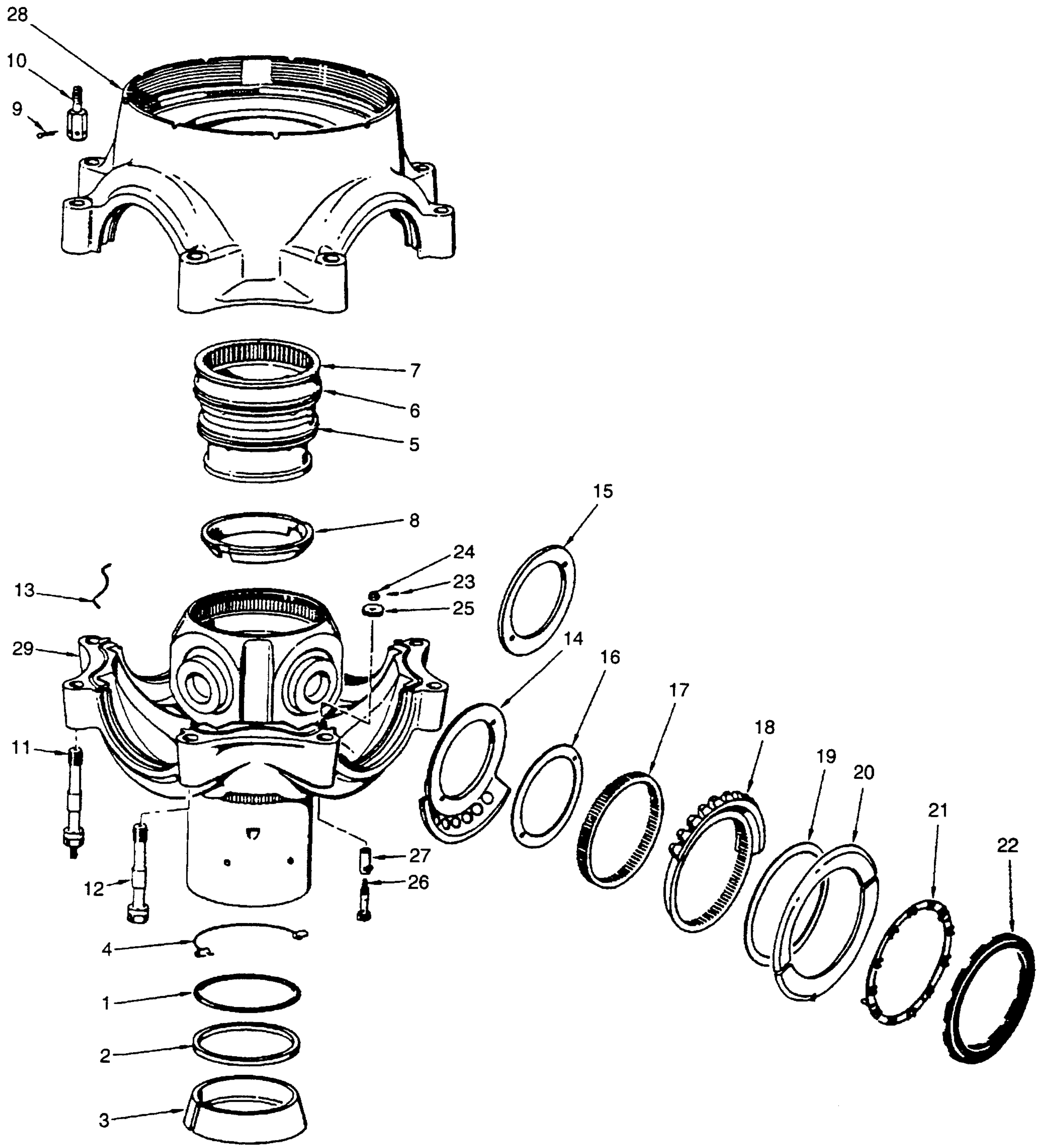


Figure 20. Propeller Barrel Assembly.

areas where coating is not desired. In addition, the rear half is too large to be fixtured to the stationary rack, but is an ideal configuration for use with the rotary parts rack.

During Phase II of this program, MCAIR designed and fabricated a fixture for the C-130 rear barrel half, Figures 7 and 8. The fixture attaches the part to the rotary parts rack and masks areas on the part which are not to be coated. The following processing parameters were verified during a Phase III demonstration run:

- Fifteen-minute glow discharge clean period.
- A 3.5 grams/minute wire-feed rate fed into each evaporator (boat).
- With the rear barrel half held stationary, the boat rack was cycled from the front to the rear of the coater and back at its fastest speed, 60 inches/minute.
- The part was rotated 180° and coated again at the fastest rack speed.
- The boat rack speed was reduced to 25 inches/minute, and the part was coated an additional four cycles with the part being indexed 90° after each boat rack cycle.

Total coating time was approximately 40 minutes. The total cycle time to evacuate the coater, glow discharge clean, coat the part, and vent the coater to atmospheric pressure was 90 minutes.

Although the demonstration was successful, additional coating runs optimized and refined part handling, coating thickness, and processing time. The optimized parameters were incorporated into the production procedure card.

WR personnel, pleased with the coating results, manufactured eight more fixtures. Coater cycle time is the same whether one or up to eight rear barrel halves are coated simultaneously. Productivity gains with the additional fixtures are presented later in this section.

Both the front and rear barrel halves were glass-bead-peened at 40 psi and exhibited excellent coating adhesion and coverage (Figure 21).

o Barrel Bolts - The C-130 propeller barrels halves are held together by eight bolts, items 11 and 12 of Figure 20. The barrel bolts have a raised area in the center of the bolt, as shown in Figure 22. WR Tech Orders required 0.0005 to 0.0006 inch of cadmium on this area which has a before plate tolerance spread of only 0.0005 inch. The rest of the bolt is plated with 0.0003 inch of cadmium. The plated bolt has an interference fit of 0.0000 to 0.0012 inch when installed in the barrel halves.

To qualify IVD aluminum for this application, MCAIR assisted a WR effort to determine whether barrel or rack fixturing produced the best coating thickness distribution and repeatability. In addition, the effects of grit blasting, grit blast pressure, glass bead peening, and glass-bead peen pressure were evaluated. The following conclusions were drawn:

- Rack fixturing is necessary to meet stringent thickness control and surface quality requirements. Barrel fixturing, which is normally used for fasteners, is not recommended for these particular bolts. Best results were obtained with the bolts racked vertically above the boats.

- The strip/cleaning procedures must maintain the tight tolerance requirement for the raised area on the barrel bolt.

- Grit blasting with coarse, 30 mesh sand was totally unacceptable. Excessive metal was removed, leaving the bolt undersize and out-of-round.

MCAIR uses a siphon-type grit blaster to clean fasteners with 220 aluminum-oxide grit without a significant change in the fastener diameter.

Although WR uses a similar 180 size aluminum-oxide grit, their pressure-type, walk-in grit blaster with a large 0.50 inch ID nozzle is designed to rapidly clean large objects where minor metal removal is acceptable. However, metal removal was excessive for the close-tolerance barrel bolts. The average

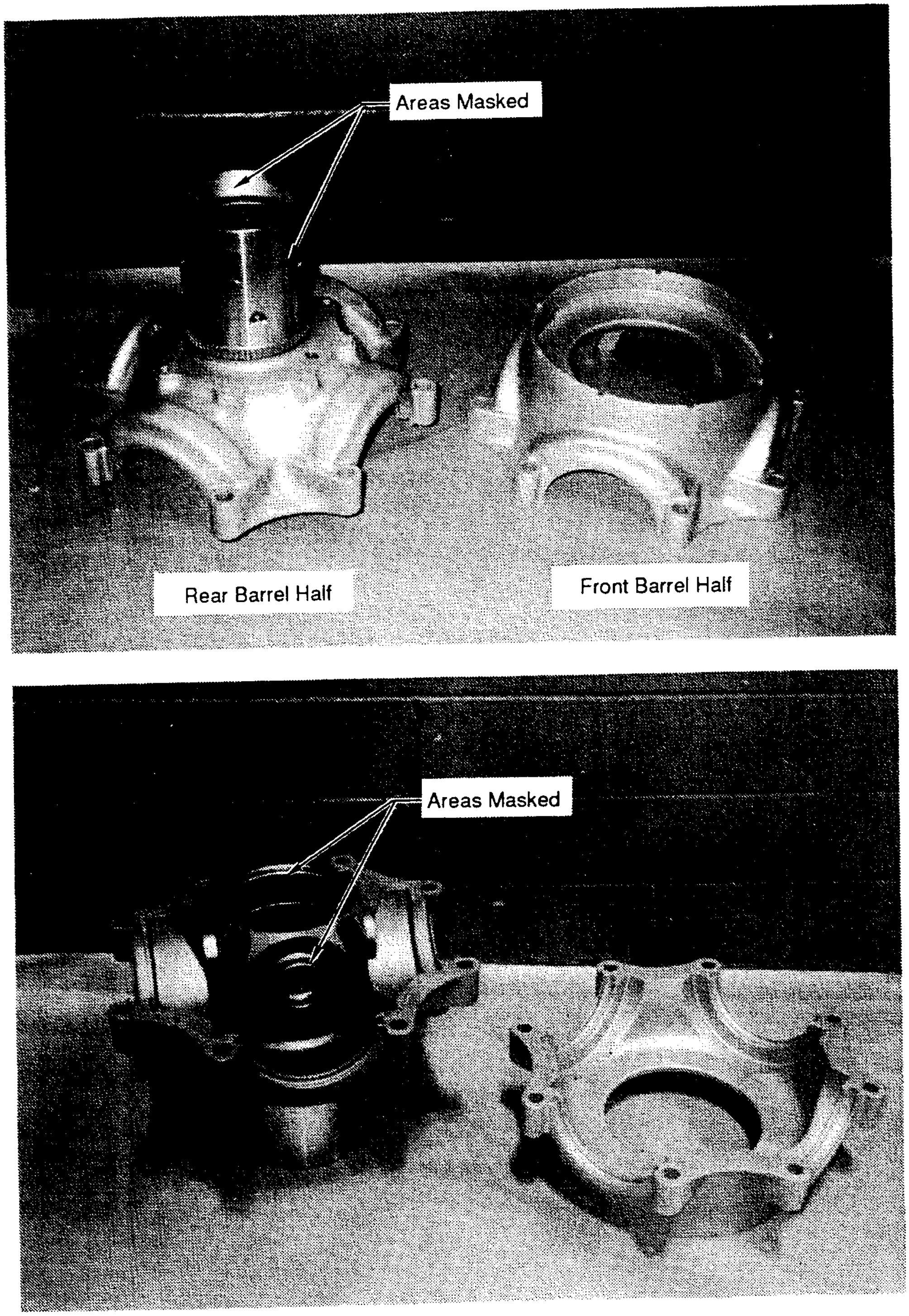


Figure 21. C-130 Front and Rear Propeller Barrel Halves IVD Aluminum-Coated, Glass-Bead-Peened, and Chemical-Conversion-Coated.

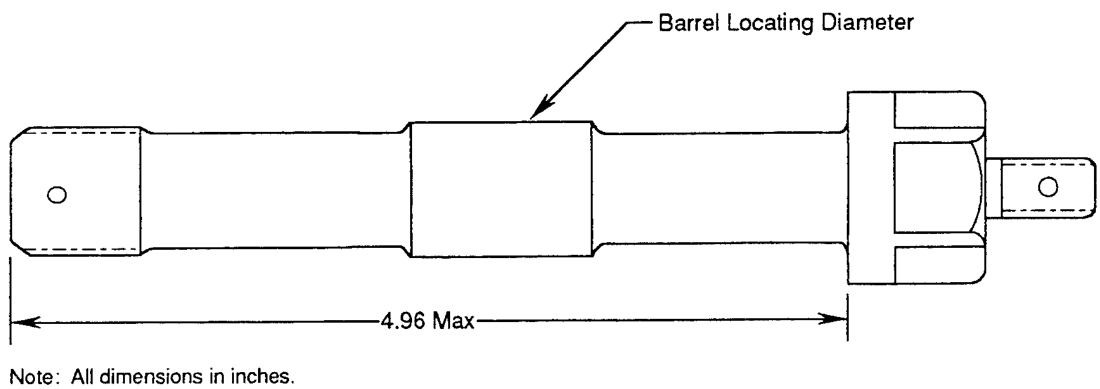


Figure 22. Typical Barrel Bolt.

reduction in bolt diameter was 0.0010 inch for 16 bolts grit blasted at 90 psi. The test was repeated at 60 psi with an average reduction in bolt diameter of 0.0008 inch. Blast pressures lower than 60 psi are not effective for this type of grit blaster.

The use of a cabinet-type, low-pressure grit blaster at WR utilizing a 0.12 inch ID nozzle did not appreciably change (0.0001 inch maximum) the barrel bolt diameter during grit blasting. Coating adhesion was excellent on the bolts cleaned in this grit blaster.

WR typically uses mechanical cleaning with glass beads to remove cadmium from many parts. Sixteen barrel bolts were glass-bead peened at 90 psi in the pressure-type, walk-in peener with 0.5 inch ID nozzle. After removal of the cadmium, 11 bolts were below the minimum bolt diameter by an average of 0.0004 inch. Additional tests verified that the high pressure glass-bead peening was removing metal from the barrel bolts. Chemical removal of the cadmium did not reduce the barrel bolt diameter.

The Work Control Document was modified to define acceptable cadmium strip and mechanical cleaning procedures for the barrel bolts. Fixturing requirements were added to the production procedure card.

o Bolts and Fasteners - Because of the long lead times to obtain small quantities of fasteners needed during overhaul of aircraft, WR has obtained equipment to manufacture small lots of fasteners. Public Law 101-592, Fastener Quality Act, regulates the testing, certification, and distribution (sale) of domestic and imported fasteners. It requires WR to perform extensive tests on these fasteners to certify them to applicable fastener specifications.

MCAIR assisted a WR effort to compare cadmium and IVD aluminum on NAS 1205-34 (100° Close Tolerance Head and Shank, 160,000 PSI Short Thread) bolts in the areas of coating thickness, adhesion, and uniformity.

Dimensional tolerances of the coated bolts were checked with a Johnson Gage. The Johnson Gage allows the functional size, pitch diameter, and lead/angle to be compared to established values for a finished bolt. Five IVD-aluminum-coated bolts tested for dimensional tolerances were within Johnson Gage limits. Cadmium plating builds up on edges or sharp protrusions and thins out in recesses and corners. WR reported that thread tolerance requirements were difficult to hold for cadmium-plated fasteners. In addition, metallographic mounts were prepared to examine the coating adhesion, thickness, and distribution on the threads. The WR laboratory reported better coating distribution on the threads of IVD-aluminum-coated bolts than of the threads of cadmium-plated bolts. Two earlier attempts to cadmium-plate bolts after chemical precleaning produced unacceptable adhesion. There were no adhesion problems with the IVD aluminum coated bolts.

Based on superior adhesion and thickness distribution with IVD aluminum coating, a program was then initiated to establish IVD aluminum coating parameters for all fasteners manufactured at WR.

WR precleans fasteners by vapor degreasing and light grit blasting at 40 psi with 180 aluminum-oxide grit. The fasteners are then loaded into a single or dual-barrel coater accessory and positioned in the IVD coater as shown in Figure 23. During glow discharge cleaning and coating, the fasteners are slowly tumbled in the rotating barrel(s) producing uniformly coated parts.

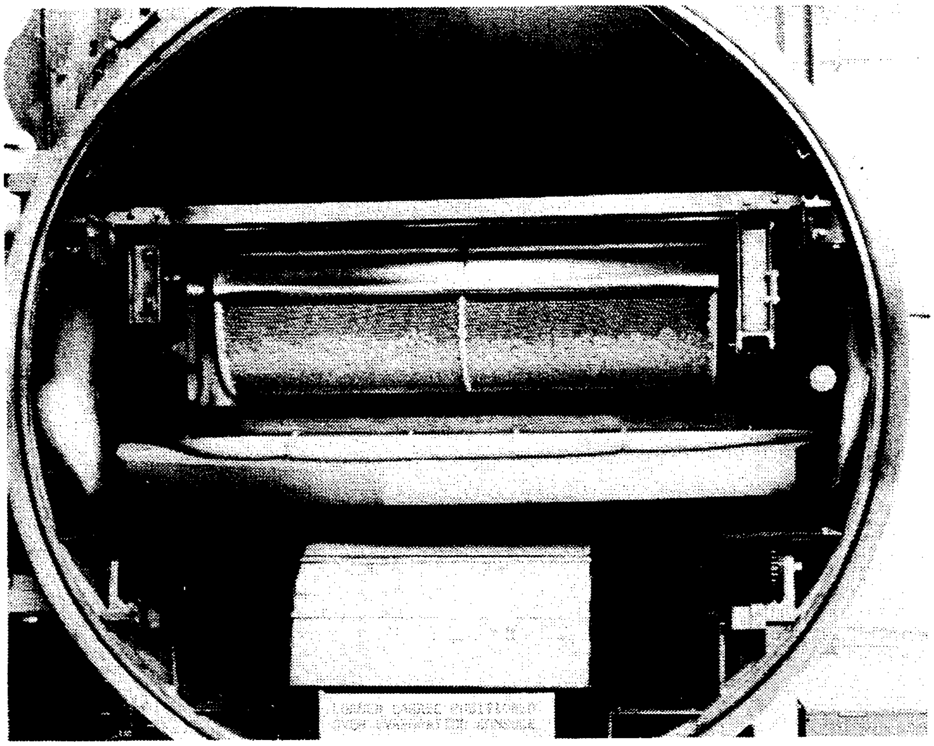


Figure 23. IVD-Aluminum-Coated Fasteners in a Dual Barrel Coater Accessory.

Initial coating runs produced rougher than desired coatings on the fasteners. In determining the cause of the rough coating, WR evaluated the effect of the following variables on fastener coating quality; fastener preclean, barrel cleanliness, coating time, and barrel rotational speed. For comparison, WR sent fasteners to MCAIR where slightly different equipment is used to clean and coat the fasteners. At MCAIR, the fasteners are ultrasonically cleaned and then grit blasted in a rotating barrel at 35 psi using 220 aluminum-oxide grit. The fasteners are coated in an IVD coater designed for large quantities of fasteners. The MCAIR coater allows fasteners to be loaded into and out of the vacuum system without the necessity of venting the coater to atmospheric pressure.

WR found barrel rotational speed to be the parameter affecting coating roughness the most. They obtained smooth coatings with barrel rotation at 0.5 to 1.0 revolution per minute (RPM). MCAIR coated four lots of WR fasteners, all with smooth coatings, using a 1.0 RPM barrel rotational speed.

During April, WR further substantiated these findings by coating fasteners with barrel rotational speeds of 1.0 and 2.0 RPM, holding all other equipment and coating parameters constant. Fastener coating at 2.0 RPM, although acceptable, was rougher than at 1.0 RPM. WR has decided on barrel rotational speeds of either 0.5 or 1.0 RPM, with 1.0 RPM for larger quantities of fasteners.

Subsequent production runs using rotational speeds of 0.5 and 1.0 RPM have produced smooth, adherent coatings that satisfied coating thickness requirements on the shank (as determined from polished mounts of cross-sectioned fasteners) and on the threads (as determined from Johnson Gage measurements of the pitch and functional thread diameters as well as from polished mounts of the coated threads).

3. Verification of Coating Conformance

a. Significance

MIL-C-83488 acceptance requirements are based on the following: coating appearance, coverage, adhesion, thickness, corrosion resistance, and substrate (part) hardness. These requirements are easily satisfied by rigid adherence to standard equipment operation and production procedure card instructions. Coating that meets these requirements is the basis of the favorable IVD aluminum to cadmium functional comparison presented in the Phase I database handbook (Reference 1). Phase III was designed to make this level of coating quality the norm at the WR-ALC.

b. Progress

o Quality Assurance - The use of production procedure cards (Figure 16) was implemented at WR during Phase III. Close compliance to procedure card instructions assures consistent, quality coating. High quality coatings are being verified at WR by the following Section IV quality checks which were also implemented during Phase III.

- Coating Appearance
- Coating Coverage
- Coating Adhesion
- Coating Thickness
- Substrate Hardness

o Implementation Log - MCAIR initiated the use of an implementation log to track "what has been accomplished". The log (Table 16) documents that a procedure has been prepared for a particular part; coating procedure and quality assurance of the coating verified; supplemental processing defined, if needed; and specific fixturing designed and procured/fabricated, if needed. The implementation log was updated monthly to reflect current part change-over to IVD aluminum.

4. C-130 Barrel Hub Productivity Gains

a. Significance

Use of state-of-the-art equipment and specialized fixturing can increase the efficiency of the IVD aluminum coating process thereby allowing significant productivity gains to be established relative to older IVD aluminum coating equipment as well as to cadmium plating. During Phase II of this program, an efficient, state-of-the-art IVD aluminum coater was installed at WR.

TABLE 16. IMPLEMENTATION LOG.

Part Information			IVD Applied		Coating Procedure		Supplemental Processing	Specific Fixturing
Number	Name	Program	Class	Type	Prepared	Verified		
546419	Thrust Ring	C-130	1	II	Yes	Yes	No	No
3P61558-101	Pylon Fitting, Aft. Engine Mount (L)	C-141	1	II	Yes	Yes	No	No
3P61558-102	Pylon Fitting, Aft. Engine Mount (R)	C-141	1	II	Yes	Yes	No	No
3P61552-101	Pylon Fitting, Female Alignment Fitting, Bellmouth	C-141	1	II	Yes	Yes	No	No
3P61540-101	Pylon Fitting, Thrust Link Aft. Mount	C-141	1	II	Yes	Yes	No	No
389727-1	Reinforcement Plate, Vertical Beam	C-130	1	II	Yes	Yes	No	No
389727-2	Reinforcement Plate, Vertical Beam	C-130	1	II	Yes	Yes	No	No
537297	Dome Cap	C-130	Threads 3 Other Areas 2	II II	Yes	Yes	No	No
69C32794	Pylon Fitting, Thrust Link	C-141	1	II	Yes	Yes	No	No
	Angles	C-141	1	II	Yes	Yes	No	No
520007	Washer	C-130	3	II	Yes	Yes	No	No
3F32086-103	Nut, Trunion	C-141	Threads 3 Other Areas 2	II II	Yes	Yes	No	No
3W01020-101	Strut Assembly	C-141	1	II	Yes	Yes	No	No
3W01021-101	Strut Assembly	C-141	1	II	Yes	Yes	No	No
3W01020-102	Strut Assembly	C-141	1	II	Yes	Yes	No	No
68A115104	Rib, Wing Outboard Torque Box	F-15	1	II	Yes	Yes	No	No
3W01021-102	Strut Assembly	C-141	1	II	Yes	Yes	No	No
3G10202-103	Link, Main Landing Gear (MLG) Bellcrank Assembly	C-141	1	II	Yes	Yes	No	No

TABLE 16. IMPLEMENTATION LOG.
(CONTINUED)

Part Information			IVD Applied		Coating Procedure		Supplemental Processing	Specific Fixturing
Number	Name	Program	Class	Type	Prepared	Verified		
3G10202-104	Link, MLG Bellcrank Assembly	C-141	1	II	Yes	Yes	No	No
3G10202-103	Upper Retainer Half, MLG Bellcrank Assy	C-141	1	II	Yes	Yes	No	Yes
3G10202-104	Upper Retainer Half, MLG Bellcrank Assy	C-141	1	II	Yes	Yes	No	Yes
3G10202-103	Lower Retainer Half, MLG Bellcrank Assy	C-141	1	II	Yes	Yes	No	Yes
3G10202-104	Lower Retainer Half, MLG Bellcrank Assy	C-141	1	II	Yes	Yes	No	Yes
3G10202-103	Inoard and Outboard Nut, MLG Bellcrank Assembly	C-141	1	II	Yes	Yes	No	No
3G10202-104	Inoard and Outboard Nut, MLG Bellcrank Assembly	C-141	1	II	Yes	Yes	No	No
3G10202-103	Ball Shaft, MLG Bellcrank Assembly	C-141	1	II	Yes	Yes	No	Yes
3G10202-104	Ball Shaft, MLG Bellcrank Assembly	C-141	1	II	Yes	Yes	No	Yes
3P61554-101	Pylon Fitting, Bulkhead Assy	C-141	1	II	Yes	Yes	No	No
388174-1	Shelf Bracket Assy	C-130	1	II	Yes	Yes	No	No
546418	Dome Retainer Nut	C-130	3	II	Yes	Yes	No	No
865891-10	Jack Support	C-141	1	II	Yes	Yes	Yes	No
72-SKA-B-77A	Wing Attach Fitting	C-141	1	II	Yes	Yes	No	No
72-SKA-B-77B	Wing Attach Fitting	C-141	1	II	Yes	Yes	No	No
72-SKA-B-77C	Wing Attach Fitting	C-141	1	II	Yes	Yes	No	No
72-SKA-B-77D	Wing Attach Fitting	C-141	1	II	Yes	Yes	No	No
3F31009-109	Link Attach	C-141	1	II	Yes	Yes	No	No
3P61551-105	Side Load Fitting	C-141	1	II	Yes	Yes	No	No

TABLE 16. IMPLEMENTATION LOG. (CONTINUED)

Part Information			IVD Applied		Coating Procedure		Supplemental Processing	Specific Fixturing
Number	Name	Program	Class	Type	Prepared	Verified		
3P61551-107	Side Load Fitting	C-141	1	II	Yes	Yes	No	No
140487-001	Covers and Housings		1	II	Yes	Yes	No	No
549773	BPO Ringlock		1	II	Yes	No	No	No
3F32085-103	Nut	C-141	Threads 3 Other Areas 2	II II	Yes	Yes	No	No
352421-13	Pilot Tube Assembly	C-130	1	II	Yes	No	No	No
	Drag Pin	C-130	3	II	Yes	Yes	No	No
8946866-01	Reinforcement Plate	C-130	1	II	Yes	Yes	No	No
8946866-02	Reinforcement Plate	C-130	1	II	Yes	Yes	No	No
68A327202-2003	Hinge Pin	F-15	3	II	Yes	Yes	No	Yes
3G11508-109	Nut	C-141	Threads 3 Other Areas 2	II	Yes	Yes	No	No
3F32087-103	Nut	C-141	Threads 3 Other Areas 2	II	Yes	Yes	No	No
3F32084-103	Nut	C-141	Threads 3 Other Areas 2	II	Yes	Yes	No	No
353512-1	Ring	C-130	1	II	Yes	Yes	Yes	No
338018-7	Strap	C-130	1	II	Yes	Yes	No	No
3308508-1		C-130	1	II	Yes	Yes	No	No
AN121556	Nut		3	II	Yes	Yes	No	No
549735	Nut		3	II	Yes	Yes	No	No
549736	Cap		3	II	Yes	Yes	No	No
3W21253-101	Bushing		3	II	Yes	Yes	No	No
3P61578-105	Bracket		3	II	Yes	Yes	No	No
3P61578-107	Bracket		3	II	Yes	Yes	No	No

TABLE 16. IMPLEMENTATION LOG. (CONTINUED)

Part Information			IVD Applied		Coating Procedure		Supplemental Processing	Specific Fixturing
Number	Name	Program	Class	Type	Prepared	Verified		
	Flap, Center Wing (Miscellaneous Parts Listed Below)							
345217-5L	Spar Cap	C-130	3	II	Yes	Yes	No	No
345217-5R	Spar Cap	C-130	3	II	Yes	Yes	No	No
345218-5L	Spar Cap	C-130	3	II	Yes	Yes	No	No
345218-5R	Spar Cap	C-130	3	II	Yes	Yes	No	No
351902-1	Bolt	C-130	3	II	Yes	Yes	No	No
363731-1	Bushing Retainer	C-130	3	II	Yes	Yes	No	No
363732-1	Bushing Retainer	C-130	3	II	Yes	Yes	No	No
363733-1	Bushing Retainer	C-130	3	II	Yes	Yes	No	No
363734-1	Bushing Retainer	C-130	3	II	Yes	Yes	No	No
38805-1	Shelf Bracket	C-130	1	II	Yes	Yes	No	No
3F11723-101	Spring		3	II	Yes	Yes	No	No
	Repair Member	C-130	1	II	Yes	Yes	No	No
	Repair Member	C-130	1	II	Yes	Yes	No	No
AN148865	Bolt, Allen Head		3	II	Yes	Yes	No	No
536385-1	Barrel, Rear (Tailshaft)	C-130	1	II	Yes	Yes	No	Yes
536385-1	Barrel, Front	C-130	1	II	Yes	Yes	No	No
537036	Stud Extension	C-130	Threads 3 Other Areas 2	II	Yes	Yes	No	No
756514-101	Aileron Hinge Bolt	C-141	3	II	Yes	Yes	No	No
3C24429-107	Push Rod	C-141	1	II	Yes	Yes	No	No
3F11309-110	Fitting	C-141	1	II	Yes	Yes	No	No
648R796-H02	Lug		1	II	Yes	Yes	No	No
3P32027-103	Engine Link	C-141	1	II	Yes	Yes	No	No

TABLE 16. IMPLEMENTATION LOG.
(CONTINUED)

Part Information			IVD Applied		Coating Procedure		Supplemental Processing	Specific Fixturing
Number	Name	Program	Class	Type	Prepared	Verified		
68B320137	Washer	F-15	3	II	Yes	Yes	No	No
68A115102	Rib, Wing	F-15	1	II	Yes	Yes	No	No
68A115103	Rib, Wing	F-15	1	II	Yes	Yes	No	No
68A115142	Rib, Wing	F-15	1	II	Yes	Yes	No	No
537034	Barrel Bolt	C-130	2	II	Yes	Yes	No	No
537035	Barrel Bolt	C-130	2	II	Yes	Yes	No	No
553505	Retainer		3	II	Yes	Yes	No	No
X8331771	Retainer	C-141	1	II	Yes	Yes	No	No
3F11390-103	Receptacle		1	II	Yes	Yes	No	No
3W01134-101	Fitting, Tie Down		1	II	Yes	Yes	No	No
312303-1	Bracket		1	II	Yes	Yes	No	No
3G11520-127	Bellcrank	C-141	1	II	Yes	Yes	No	No
3G11520-128	Bellcrank	C-141	1	II	Yes	Yes	No	No
RC-18 -101B	Spring	ALE-24	3	II	Yes	Yes	No	No
	Repair Angle	C-141	1	II	Yes	Yes	No	No
	Repair Angle	C-141	1	II	Yes	Yes	No	No
7329904-04	Chine Cap Repair	C-130	1	II	Yes	Yes	No	No
	Repair Part		1	II	Yes	Yes	No	No
30-1091	Spring	ALE-27	3	II	Yes	Yes	No	No
30-1092	Spring	ALE-27	3	II	Yes	Yes	No	No
30-1093	Support Equalizer	ALE-27	3	II	Yes	Yes	No	No
30-1101	Spacer	ALE-27	1	II	Yes	Yes	No	No
30-1174	Spring Guides	ALE-27	3	II	Yes	Yes	No	No
342786	Spacer-Flap, Center Wing	C-130	1	II	Yes	Yes	No	No
3W21131	Stiffner	C-141	1	II	Yes	Yes	No	No

TABLE 16. IMPLEMENTATION LOG.
(CONCLUDED)

Part Information			IVD Applied		Coating Procedure		Supplemental Processing	Specific Fixturing
Number	Name	Program	Class	Type	Prepared	Verified		
	Flap, Outer Wing Parts							
351902	Bolt	C-130	3	II	Yes	Yes	No	No
NAS1104-64	Bolt	C-130	3	II	Yes	Yes	No	No
NAS1105-64D	Bolt	C-130	3	II	Yes	Yes	No	No
AN177H-15	Bolt	C-130	3	II	Yes	Yes	No	No
AN176H-15	Bolt	C-130	3	II	Yes	Yes	No	No
353734-1	Bushing Retainer	C-130	3	II	Yes	Yes	No	No
NAS1022-A8	Nut	C-130	3	II	Yes	Yes	No	No
NAS1022-A14	Nut	C-130	3	II	Yes	Yes	No	No
342787	Spacer	C-130	1	II	Yes	Yes	No	No
NAS4200-8-160	Spacer	C-130	1	II	Yes	Yes	No	No
351900	Lock	C-130	1	II	Yes	Yes	No	No
342793	Lock	C-130	1	II	Yes	Yes	No	No
342786T	Spacer	C-130	1	II	Yes	Yes	No	No
340179-3	Shim	C-130	1	II	Yes	Yes	No	No
340179-4	Shim	C-130	1	II	Yes	Yes	No	No
365962-IL	Stop	C-130	1	II	Yes	Yes	No	No
365962-IR	Stop	C-130	1	II	Yes	Yes	No	No
	Lockout Lever	C-141	3	II	Yes	Yes	No	No

This system includes all mechanical and electrical refinements identified by MCAIR in the design, fabrication, and operation of IVD aluminum coaters including a cryopump system. The cryopump process involves a 50-foot long, 5/8-inch diameter copper coil installed in the top quadrant of the coater. The coil is cooled from room temperature to below -100°C by a refrigeration system in less than 3 minutes. Water vapor molecules are effectively removed from the coater by being frozen to the cold surface. The cryopump typically reduces pumpdown time by 50-70 percent, saving 30 minutes or more. Also during Phase II, a fixture was designed to mask and fixture C-130 rear barrel hubs to the rotary parts rack. WR fabricated eight additional fixtures during Phase III.

b. Progress

Productivity gains were established in several areas at WR. A productivity gain was established using state-of-the-art WR coating equipment/accessories (Phase II fixture, cryopump, rotary rack) compared to conventional WR coating equipment (no fixture, no cryopump, stationary rack) to process C-130 propeller rear barrel half details. Also, a productivity gain was realized at WR by processing the C-130 propeller barrel halves with state-of-the-art IVD equipment in relation to processing the parts with cadmium.

o State-of-the-art versus conventional processing - The time and labor requirement to process eight rear barrel hubs in the WR state-of-the-art coater with a cryopump, rotary rack, and Phase II barrel half fixtures is shown in Table 17. For comparison, the time and labor requirement to process eight rear barrel hubs in the WR conventional coater with no cryopump, rotary rack, or Phase II barrel hub fixture is shown in Table 18.

TABLE 17. PROCESSING TIME FOR COATING EIGHT REAR BARREL PROPELLER HALVES IN WARNER ROBINS STATE-OF-THE-ART IVD ALUMINUM COATER.

Item	Process Time (minutes)	Labor (Persons)	Labor Time (Person-minutes)
Mask and Load	92	2.0	184
Process Hubs in Coater[a]			
Pumpdown	40	0.2	8
Glow Discharge Clean	15	0.5	8
IVD Aluminum Coat	40	1.0	40
Cool Hubs and Vent	10	1.0	10
Unload and Demask	64	2.0	128
Total Process and Labor Times	261		376
Process Time Per Hub	33		
Total Labor Time Per Hub			47

a For Warner Robins state-of-the-art IVD aluminum coater containing cryopump, rotary rack, and Phase II barrel half (hub) fixtures.

TABLE 18. PROCESSING TIME FOR COATING EIGHT REAR BARREL PROPELLER HALVES IN WARNER ROBINS CONVENTIONAL IVD ALUMINUM COATER.

Item	Process Time (minutes)	Labor (Persons)	Labor Time (Person-minutes)
Mask and Load			
Mask O.D. of Tail Shank	16	2.0	32
Mask 4 Hub Protrusions Per Hub	64	2.0	128
Load	40	2.0	80
Mask Tail Shank I.D.	20	2.0	40
Mask Other End I.D.	20	2.0	40
Process Hubs in Coater[a] (First Side)			
Pumpdown	90	0.2	18
Glow Discharge Clean	15	0.5	8
Coat	20	1.0	20
Cool Hubs and Vent	6	1.0	6
Turn Parts and Remask Ends	30	2.0	60
Process Hubs in Coater[a] (Second Side)			
Pumpdown	90	0.2	18
Glow Discharge Clean	5	1.0	5
Coat	20	1.0	20
Cool Hubs and Vent	6	1.0	6
Unload and Demask	48	2.0	96
Total Process and Labor Times	490		698
Process Time Per Hub	61		
Total Labor Time Per Hub			87

a For Warner Robins state-of-the-art IVD aluminum coater without cryopump, rotary rack, and Phase II barrel half (hub) fixtures.

The productivity gains using the state-of-the-art system compared to the conventional coater are:

- Processing time: 46 percent
- Labor: 46 percent

o State-of-the-art IVD aluminum versus cadmium plating - The productivity gain realized by changing from cadmium plating to IVD aluminum coating for the C-130 propeller barrel was calculated by comparing the respective time and labor requirement to process both the front and rear barrel halves. (Preclean and post-coat/plate processing that is common to both processes is not included.) Cadmium-plate time and labor requirements are based on interviews with WR processing personnel.

The time and labor requirement to process eight rear barrel and eight front barrel halves with state-of-the-art IVD aluminum is presented in Tables 19 and 20, respectively. Total labor and processing time to coat a complete barrel assembly is the sum of the labor and processing times for the front and rear barrel halves.

TABLE 19. IVD ALUMINUM PROCESSING TIME FOR EIGHT REAR PROPELLER BARREL HALVES.

Item	Process Time (minutes)	Labor (Persons)	Labor Time (Person-minutes)
Mask and Load	92	2.0	184
Process Hubs in Coater[a]			
Pumpdown	40	0.2	8
Glow Discharge Clean	15	0.5	8
IVD Aluminum Coat	40	1.0	40
Cool Hubs and Vent	10	1.0	10
Unload and Demask	64	2.0	128
Glass-Bead Peen Hubs	80	1.0	80
Total Process and Labor Times	341		458
Process Time Per Hub	43		
Total Labor Time Per Hub			56

a For Warner Robins state-of-the-art IVD aluminum coater containing cryopump, rotary rack, and Phase II barrel half (hub) fixtures.

TABLE 20. IVD ALUMINUM PROCESSING TIME FOR EIGHT FRONT PROPELLER BARREL HALVES.

Item	Process Time (minutes)	Labor (Persons)	Labor Time (Person-minutes)
Load	24	2.0	48
Process Hubs in Coater[a] (First Side)			
Pumpdown	40	0.2	8
Glow Discharge Clean	15	0.5	8
Coat	22	1.0	22
Cool and Vent	6	1.0	6
Turn Hubs Over	16	2.0	32
Process Hubs in Coater[a]			
Pumpdown	40	0.2	8
Glow Discharge Clean	5	1.0	5
Coat	17	1.0	17
Cool and Vent	6	1.0	6
Unload	16	2.0	32
Glass-Bead Peen Hub	48	1.0	48
Total Process and Labor Times	255		240
Process Time Per Hub	32		
Total Labor Time Per Hub			30

a For Warner Robins state-of-the-art IVD aluminum coater containing cryopump and standard rack.

For cadmium plating, the processing time for plating a front and rear barrel half set is presented in Table 21. The cadmium-plate federal specification, QQ-P-416, requires a 23-hour bake at 375 +/- 25°F for hydrogen embrittlement relief of these high-strength steel details within 4 hours of plating. WR bakes the parts for a minimum of 23.5 hours. The barrel halves are transported from the plating area to the oven area several times per day to stay within the 4-hour requirement. There is no hydrogen embrittlement concern with the IVD aluminum process.

The productivity gains realized by changing from cadmium plating to IVD aluminum coating for the C-130 propeller barrel halves are:

- Processing Time: 95 percent
- Labor: 51 percent

TABLE 21. CADMIUM PLATE PROCESSING TIME FOR A FRONT AND REAR PROPELLER BARREL HALF SET.

Item	Process Time (minutes)	Labor (Persons)	Labor Time (Person-minutes)
Mask, Load, Plate, Unload, and Demask[a]	150	1.00	150
Hydrogen Embrittlement Relief	1,410	0.02	28
Total Process and Labor Time	1,550		178

a For former Warner Robins cadmium plating line.

Another significant item is the amount of aluminum being applied to these details which is 0.0010-0.0015 inch as opposed to about 0.0005 inch of cadmium. The added aluminum thickness will result in improved field performance.

In conclusion, WR has eliminated a hazardous waste stream, reduced processing labor and flow time (turnaround), and improved coating quality and performance by the substitution of IVD aluminum coating for cadmium plating for the C-130 barrel halves.

5. Operator/Maintenance Personnel Training

a. Significance

Trained personnel are required to ensure the successful transition from a mature ALC process like cadmium plating to a relatively new ALC process like IVD aluminum. Grit-blast personnel need to understand that adherent coatings require properly cleaned parts including proper handling of the cleaned parts. To apply quality coatings, coater personnel need to thoroughly understand the importance of complying with the coating procedure delineated on the production procedure cards, be able to operate the IVD aluminum coating equipment efficiently, and be able to identify equipment and process problems. To meet schedules and ensure proper coater operation, maintenance personnel need to understand the equipment/process sufficiently to quickly identify and correct problems that occasionally occur as well as performing scheduled maintenance.

b. Progress

Throughout the contract period, MCAIR trained WR personnel in the areas of IVD coater and accessory operation, coater maintenance, and troubleshooting. For problems associated with coater/accessory operation, the problem, troubleshooting technique used to identify the problem, and the solution to the problem were discussed with as many WR personnel as possible. Nine operators personnel representing the three production shifts at WR are now proficient in the use of the IVD process and equipment.

o Personnel Training

After installation of the WR state-of-the-art coating during Phase II of this program, MCAIR trained WR electronic engineers and electrical/electronic maintenance technicians on subjects shown in Table 22. MCAIR also trained WR operators and mechanical maintenance/engineering technicians on the subjects shown in Table 23. This training was extended as required throughout the Phase III effort.

TABLE 22. COATER ELECTRICAL MAINTENANCE TRAINING.

Item	Air Logistics Centers[a,b]	
	WR	OO
• Review of Electrical and Electronic Systems, Including Wiring Diagrams and Drawings	X	X
• Troubleshooting Procedures for the Current Sources and Control Systems	X	X
• Electrical and Electronic Equipment Servicing and Care	X	X
• Adjustment Procedures (Locating Components, Adjustments to Be Made, Values to Be Measured, Equipment Required for Making Adjustments)	X	X
• Applicable Circuit Board Repair Procedures	X	X
• Recommended Motor, Switch, Relay, Solenoid, etc., Maintenance Servicing and Repair	X	X

a The Air Logistics Centers are Warner Robins (WR) and Ogden (OO).
b Training was given during Phase II, May 1990.

Key:
x Item was discussed during training.

TABLE 23. COATER MECHANICAL MAINTENANCE TRAINING.

Item	Air Logistics Centers [a,b]	
	WR	OO
A Review of Mechanical Diagrams and Drawings	X	X
Component Location and Function	X	X
Troubleshooting Procedures and Techniques	X	X
Repair Procedures	X	X
Assembly/Disassembly Procedures	X	X
Adjustments - (How, When and Where)	X	X
Preventative Maintenance Procedures	X	X
Valve Location and Functions	X	X
Valve Adjustment and Maintenance Procedures	X	X
System Operation	X	X
Potential Operation Problems	X	X
Potential Maintenance Problems	X	X

a The Air Logistics Centers are Warner Robins (WR) and Ogden (OO).
b Training was given during Phase II, May 1990.

Key:
x Item was discussed during training.

o Coater/Accessory Operation Problems/Solutions

- Foreline Valve - A coater foreline valve leaked due to a damaged o-ring. Replacement of the o-ring did not effectively correct the problem. However, the replacement o-ring had a durameter hardness 15 points higher than the original o-ring, which prevented a reliable seal against leaks into the vacuum system. Replacement with a softer o-ring corrected the problem.

- Cryopump - Several problems occurred with the coater cryopump: refrigeration unit kick-off, sticking refrigeration solenoid, broken coil braze joints, and a vacuum leak at the cryopump coil passthrough into the coater. A solution was found for each problem.

The refrigeration system kick-off problem was caused by the compressor being too cool. Water flow to the refrigeration unit is normally adjusted to maintain a warm exit temperature from the compressor. However, the valve in the water line was found to be wide open. After readjusting the water valve, no further shutdown on the refrigeration unit occurred.

Although there are instructions to throttle the water flow to the refrigeration unit by manual adjustment of the water valve, a permanent method to control the compressor temperature is desirable. A water flow controller that maintains a constant water compressor exit temperature was recommended to WR (Reference 12).

The problem with the refrigeration solenoid sticking open caused the cryocoil in the coater to cool down at atmospheric pressure allowing flow of the refrigerant through the coil while the coater was in the "Standby" mode. During Standby, no flow of refrigerant should occur through the coil. The manufacturer suggested that oil from the compressor may have been swept into the valve during refrigeration unit kick-off. After several on-and-off cycle sequences, the solenoid closed and presented no further problems. WR was advised to obtain a spare solenoid, in case the problem reoccurred. In addition, instructions directed at the solenoid problem and the refrigeration unit kick-off problem were provided (Reference 13).

Some of the braze joints between turns of the cyrocoil had broken, causing additional problems. This allowed the coil to thermally short to its support structure, decreasing efficiency. The coil turns were ridigized using clamps. Teflon insulators were added to prevent the thermal short between the coil and support structure.

WR also experienced an increase in coater pump-down time in this period. Probable causes such as a coater vacuum leak(s) or cryocoil refrigerant leak(s) were investigated. A high vacuum leak check of the cryocoil vacuum passthrough using methyl ethyl ketone (MEK) revealed a small air leak in the braze joint at the copper coil/stainless steel passthrough interface indicating either a pinhole or small crack. The joint was rebrazed and no further evidence of a vacuum leak was detected. In addition, the braze joint and cryocoil were checked for refrigerant leaks using a halogen leak detector. No leak was detected.

- Flow Regulator - WR had a low pressure problem caused by a faulty flow regulator in the system that supplies gaseous nitrogen to the

IVD aluminum coaters. Gaseous nitrogen is used to prevent aluminum-alloy parts from overheating during coating. Aluminum-alloy parts are coated in steps to achieve the final coating thickness. Between coating steps, the parts are cooled from coating temperature to room temperature convectively by directing a nitrogen gas flow across the parts. If the gas delivery system pressure is low, part cooling is not performed efficiently. MCAIR recommended an increased cooling-time procedure until replacement of the flow regulator (Reference 14).

SECTION VII

IVD ALUMINUM IMPLEMENTATION ASSISTANCE AT THE OTHER ALCs

A. SUMMARY

While it was planned to bring all of the ALCs together during the WR program, there are distinct divergencies of ALC responsibility as well as different "areas of concern" in substituting for cadmium. To address these areas, MCAIR visited each of the other four ALCs to provide some individual attention to help meet the ultimate goal of the elimination of cadmium processing at all of the ALCs. The ALCs at Ogden, Oklahoma City, Sacramento, and San Antonio have all expressed the desire to reduce and/or eliminate the use of cadmium during this program. MCAIR has recommended IVD aluminum as the replacement process. Each of the ALCs have one or more IVD aluminum coaters. Although the other four ALCs have different "areas of concern" from WR-ALC, the Phase I effort showed that over 80 percent of the cadmium-plated parts could be changed easily to IVD aluminum coatings without any problems. Phase II efforts identified solutions for "areas of concern". Supplemental coatings can be used to augment IVD aluminum coatings in deep bores and recesses. Lubricants can be used to adjust for lubricity difference between finishes. Thicker aluminum coatings can be used for erosion resistance concerns. MCAIR spent 2 weeks at each ALC. During the first week, additional training was provided in the areas of IVD coater and accessory operation, coater maintenance, and troubleshooting. During the second week, procedures were developed and verified by demonstration runs for parts selected by the ALCs that exhibited some concern. The OC-ALC has completely replaced cadmium processing with IVD aluminum and some usage of a nickel-zinc electroplate process. The SM-ALC has plans to completely replace cadmium with IVD aluminum. The SA and OO ALCs have reduced their usage of cadmium with increased usage of IVD aluminum. There are a few parts at OO that are too large for processing in existing equipment. To totally eliminate cadmium, Ogden will require either larger equipment or investigate another coating process for those few parts.

MCAIR believes the "hands-on" assistance provided the other ALCs provided personnel with a better understanding of their IVD coaters, the coating process, coating procedure development, and usage of production procedure cards for process control.

B. TASK

MCAIR provided assistance to the efforts of the OC, OO, SM, and SA ALCs to implement the use of IVD aluminum during a 2-week visit to each site. MCAIR responded to the requests of each ALC to determine the best utilization of time.

1. Other ALC/Assistance

a. Significance

Demonstration of the acceptability of IVD aluminum coating for the various ALC applications that now require cadmium plating will help achieve the ultimate goal of elimination of cadmium processing at each ALC. This goal is achievable by utilizing the approach employed at WR. A "hands-on" coordination with ALC responsible departments will be employed. Coating demonstrations, equipment and processing evaluations, and training will be performed at each of the ALC sites for a 2-week period. Parts selected by each ALC will be examined for supplemental processing or fixturing needs, procedures identified by cleaning and coating the parts, and coatings/procedures evaluated. Since time at each ALC is limited, recommendations will be given to improve further processing efficiency.

b. Progress

o Coordination

- Video Conference - MCAIR participated in the ALC Engineering Seminar Series discussing "The substitution of IVD aluminum for Cadmium". The seminar was transmitted from WR's Video Teleconference Studio to personnel at the OC, OO, SM, and SA ALCs on 22 October 1991. The SM-ALC Corrosion Management

Office initiated the seminar which had the following stated objective: "Due to environmental limitations on the use of cadmium, the Air Force engineering community will be asked in the coming years to approve the use of IVD aluminum on aerospace components. MCAIR will address the benefits and limitations of substituting IVD aluminum for cadmium plating. This seminar will assist engineers in making sound engineering judgements on the use of IVD aluminum." SM reported that 41 ALC personnel participated in the seminar.

- During November, a presentation was made to each of the other four ALCs on the status of Phase III activities at WR and to outline/coordinate Phase III plans for the other ALCs. The ALC point of contact, presentation date, and number of ALC attendees are shown in Table 24.

TABLE 24. PRESENTATION OF WARNER ROBINS PHASE III ACTIVITIES TO SAN ANTONIO, SACRAMENTO, OKLAHOMA CITY, AND OGDEN AIR LOGISTICS CENTERS.

ALC	Point of Contact	Date of Presentation	Number of Attendees
SA-ALC	Ms. Nancy Stapper	November 14, 1991	10
OC-ALC	Mrs. Louise Nguyen	November 15, 1991	12
SM-ALC	Mr. Elwin Jang	November 20, 1991	12
OO-ALC	Mr. Mark Child	November 21, 1991	25

During December, MCAIR sent letters to the other ALCs summarizing the November visit and addressing action items identified during the visit (References 15 through 18). Each ALC was asked to select up to five detail parts that exhibit an area of concern(s) for replacing cadmium with IVD aluminum. MCAIR would then develop procedures for the parts and assist with part processing at each ALC during 1992.

During January, the SA, SM, and OO ALCs provided lists of candidate parts (Reference 19). The first visit was to the SA-ALC in late February.

o WR visits from the other ALCs - The other ALCs were encouraged to visit WR to observe their operational procedures, masking and fixturing techniques, rotary and barrel coater accessories, and the cryopump installation - all of which increase productivity.

Richard Newton and James Maki, responsible for coater operation/coating process at the OO-ALC, visited WR for 4 days during April 1992. Since the OO-ALC has cadmium-plated bolt applications for IVD aluminum, processing of close-tolerance fasteners and bolts was demonstrated in a barrel accessory. OO-ALC personnel witnessed Class 3 (0.0003 - 0.0005 inch thick) IVD aluminum coatings applied to threaded hardware uniformly with excellent adhesion and appearance.

Kurt Greebon, plating-shop chemist responsible for coater operation/coating process at the SA-ALC, spent 5 days at WR during March 1992. While there Kurt utilized his air-conditioning experience by participating in the analysis of WR cryopump problems. His expertise was helpful and appreciated.

Elwin Jang and Jeff Marnix, IVD Process Engineers from SM-ALC and OC-ALC, respectively, spent 2 days at WR during July 1992. They interfaced with WR coating personnel, attended the final program briefing, and witnessed a demonstration run with C-130 rear propeller halves.

- Final Program Briefing for All ALCs

MCAIR presented a final program/Phase III briefing, Reference 20, to HQ-AFCESA/RAVS, Lt. Phillip Brown, and EG&G Idaho, Inc., Pat Lange, on 9 July 1992 at WR. Elwin Jang, SM-ALC, Jeff Marnix, OC-ALC, and nine WR personnel were in attendance.

In addition, a demonstration of the WR state-of-the-art IVD aluminum coater at WR was given. Three C-130 rear propeller barrel halves were fixtured on the rotary rack using additional Phase II fixtures manufactured at WR during Phase III. The Phase II fixture was designed to mask and fixture the part to the rotary rack. The state-of-the-art coater included use of a cryopump for rapid evacuation of the coater. With the rotary rack, the parts were completely and uniformly coated on all surfaces without the need to break the vacuum and turn the parts over as required when using the stationary parts hanging rack. Productivity gains associated with state-of-the-art coating equipment/accessories are shown in Section VI.

2. San Antonio (SA)-ALC Demonstration/Assistance

MCAIR assisted the SA effort to implement the use of IVD aluminum coating for cadmium for a 2-week period beginning 24 February 1992. Coating procedures were developed and verified for several parts identified by SA. In addition, MCAIR provided training to SA personnel.

SA requested additional training to better understand the coating process equipment. Kurt Greebon, plating shop chemist, is responsible for coater operation and the coating process at SA. Kurt participated in all activities during the two weeks. Other SA personnel received training on the basis of their available.

During the first week, emphasis was placed on coater operation, maintenance, and troubleshooting training. Coater operation and maintenance items reviewed are listed in Tables 25 and 26, respectively. During the two weeks at SA, several coater problems were diagnosed and resolved. The problems and solutions are listed in Table 27.

TABLE 25. COATER OPERATIONAL TRAINING.

Item	Air Logistics Centers[a]			
	SA	SM	OC	OO
• Vacuum Level Effects on Coating Adhesion	X	X	X	X
• Machine Set Points for Automatic Pumpdown	X	X	X	X
• Wire Feed Rate and System Calibration	X	X	X	X
• Boat Rack (Evaporator Carriage) Speed and Calibration	X	X	X	X
• Recommended Practices for Masking Parts	X	X	X	X
• Mechanical Cleaning of Parts	X	X	X	X
• Chemical Cleaning of Parts	X	X	*	*
• Glass-Bead Peening of IVD Aluminum-Coated Parts	X	X	X	X
• Glow Discharge Cleaning Theory and Parameters	X	X	X	X
• Hollow-Cathode Glow Discharge Generation and Elimination	X	X	X	X
• Boat (Evaporator) Operation	X	X	X	X
• Convective Cooling Requirements and Parameters	X	X	X	X
• Moisture and Its Effect on Coating Adhesion	X	X	X	X
• Necessity for Cleaning the Standard Rack and Shields in the Coater	X	X	X	X

a The Air Logistics Centers are San Antonio (SA), Sacramento (SM), Oklahoma City (OC), Ogden (OO).

Key:

X Item was discussed during training.

* Item was not discussed during training.

TABLE 26. COATER MAINTENANCE TRAINING.

Item	Air Logistics Centers[a]			
	SA	SM	OC	OO
• Lubrication Points	X	X	X	X
• Frequency for Checking Oil Levels in Pumps and for Lubricating Components	X	X	X	X
• Wear Items and Replacements	X	X	X	X
• Adjustment Procedures for Wire Feeders	X	X	X	X
• Adjustment Procedures for Boat Rack Travel	X	X	*	X
• Adjustment Procedures for Boat Rack Slip Clutch and Pump Belts	X	X	*	*
• Possible Locations for Vacuum Leaks	X	X	X	X
• Tests for Water and Vacuum Leaks	X	X	X	X
• Cleaning Schedule for Shields and the Standard Rack	X	X	X	X
• Disassembly of the Standard Parts Rack for Cleaning	X	X	X	X
• Disassembly of the Barrel Accessory for Cleaning	*	X	X	X
• Adjustment of Set Points for Automatic Evacuation of the Coater	X	X	X	X
• Fuse Locations	X	X	*	*
• Disassembly and Cleaning of the Diffusion Pump	*	*	*	X
• Disassembly, Cleaning, and Adjustment of the Boat Clamp Holder Assembly for Improved Cooling of the Boats	*	*	*	X

a The Air Logistics Centers are San Antonio (SA), Sacramento (SM), Oklahoma City (OC), Ogden (OO).

Key:

X Item was discussed during training.

* Item was not discussed during training.

TABLE 27. COATER PROBLEMS DIAGNOSED AND RESOLVED AT SAN ANTONIO AIR LOGISTICS CENTER.

Problem	Corrective Action
• Extended Pumpdown Time	Locate and Stop Water Leak
• Excessive Foreline Pressure/Dark Coating	Clean Coater Shields and Standard Parts Rack
• Wire Feeding Too Far Out Into the Boats	Adjust Wire Feed Impingement Point Into the Boats
• Loose Boat Clamp	Retap Barrel Nut and Tighten Bolt Holding the Clamp
• Pressure Slightly High for High Vacuum Pumping and Glow Discharge Cleaning	Adjust Set Points for Automatic Pumpdown for Improved Performance and Glow Discharge Cleaning
• Boat Operation	Adjust Warmup Potentiometers to Fixed Value and Adjust Run Potentiometers for More Uniform Heating of the Boats

During the second week, coating procedures were developed and verified for the SA parts shown in Table 28.

TABLE 28. DEVELOPMENT AND VERIFICATION OF COATING PROCEDURES FOR PARTS AT THE SAN ANTONIO AIR LOGISTICS CENTER.

Part Number	Name
6794188	Link Rod Assy - Prop Control, Inter
6824476	Housing Assy Torquemeter
6826935	Arm - Prop Control, Rear
6791898	Bracket Assy - Engine Mounting Plate
6859604	Vane Assy, Compressor - 4th Stage
6859612	Vane Assy, Compressor - 12th Stage

All of these parts were vapor degreased, stripped of cadmium or nickel-cadmium, grit blasted with 220 aluminum oxide grit, and blown off with dry, filtered air. The parts were hung horizontally off the stationary parts rack 10-12 inches above the boats. Adhesion of the IVD aluminum coating was verified by glass bead peening the parts at 40 psi. The thickness of the coating was measured using an Elektro-Physik Minitest 3000. The Minitest 3000 was calibrated using a bare spot for the zero-calibration point and a 0.002 inch plastic shim for the upper-calibration point.

The 6794188 Link Rod Assembly is 44 inches long by 0.9 inch in diameter. The assembly is hollow for 16 inches on each end. The opening on each end is 0.3 inch in diameter, threaded, and opens into a 0.8-inch diameter cavity about three inches into the part. These parts were rusted badly when received. The inner cavity was too small and deep to be mechanically cleaned. A precleaning procedure was developed that required vapor degreasing, soaking in alkaline rust remover, baking, and grit blasting before acceptable coating adhesion could be obtained. Without adequately cleaning the inner cavity, outgassing, from moisture entrapment in the rust in the inner cavity, caused black, poorly adherent coating on the ends of the part. The inner cavity had been filled with MIL-C-16173 Corrosion Preventive Compound after being plated with cadmium. Although acceptable for IVD coated parts also, MCAIR recommended a procedure developed during Phase II of this program to improve corrosion resistance; namely, fill and drain with either (1) an epoxy primer and polysulfide sealant or (2) a manganese phosphate coating, waterborne epoxy primer, and a high-solid polyurethane topcoat or substitute a polysulfide sealant for the polyurethane topcoat.

The 6824476 Housing Assembly Torquemeter is a large tubular part 28.2 inches long. One end of the part has a 7.4-inch outer diameter (OD) and 5.9-inch inner diameter (ID) that tapers into a central 3.5-inch tubular section about 6.8 inches from the end of the part. The other end has a 7.0-inch OD and 5.2-inch ID that tapers into the 3.5-inch tubular section about 2.5 inches from the end of the part. The 3.5-inch diameter tubular section is 18 inches long. A precleaning procedure was developed that requires vapor degrease, high-temperature bake, and grit-blast steps. The large openings on both ends and the large diameter of the inner cavity allowed the ID of the part to be mechanically cleaned. However, since this part was coated as a two-detail assembly, baking was required to eliminate moisture entrapment in the faying surface. MCAIR recommended future disassembly before coating, as faying surfaces will always present a potential outgassing source during coating.

Hollow cathode glow discharge is an intense plasma beamed from the inside of hollow parts. It is detrimental, producing coating nonadhesion and possible overheating of coated parts. Hollow cylindrical parts may experience hollow cathode glow discharge caused by several factors; namely: an inadequately cleaned inner cavity; a cavity diameter which exceeds the glow discharge dark space thickness; too high of a coater pressure; or too high of a voltage applied to the part. SA was able to control hollow cathode discharge when processing only one part by controlling the high voltage and coater pressure. MCAIR recommends plugging the ID of the tubular section with an aluminum foil (or other) plug when coating multiple 6824476 assembles to prevent possible hollow cathode glow discharge problems. This part was coated with excellent coating adhesion and coverage.

SA Engineering chose not to use a fill-and-drain primer and sealant on the ID of this part. They thought that oiling would be sufficient. If restrained to oiling, MCAIR recommended a phosphate coating be used on the ID to hold more oil on the surface. Attempts at phosphating the part however were not successful. Black oxide coating was substituted for phosphate coating. The black oxide applied to external surfaces was removed by grit blasting with 220 aluminum-oxide grit prior to coating. The IVD aluminum coating was allowed to wrap into the ID of the tube and coat over the black-oxide coating. Adhesion of the IVD aluminum to the black oxide was excellent, passing the 40 psi glass bead peen adhesion evaluation.

No problems were experienced coating the other parts. SA commented that the coverage of the IVD aluminum coating was better than that of nickel-cadmium plating on the 4th stage and 12th stage compressor vane assemblies.

Other compressor vane assemblies, such as the 6859601 1st stage and the 6859609 9th Stage, did not have their nickel-cadmium finish stripped during the MCAIR visit. However, they are similar to the 4th and 12th stage assemblies and can be processed with the same coating procedure.

The environmental aspects of the substitution of IVD aluminum for cadmium were discussed with SA Environmental Management personnel. They are in concert with the program objective and are very interested in eliminating the usage of cadmium at the SA-ALC.

3. Sacramento (SM)-ALC DEMONSTRATION/ASSISTANCE

MCAIR provided assistance to the SM effort to implement the use of IVD aluminum coating as a replacement for cadmium during a 2-week period beginning 30 March 1992. Coating procedures were developed and verified for several parts identified by SM. In addition, MCAIR provided training to SM personnel.

Elwin Jang, IVD Process Engineer, is responsible for the coater operation/coating process at SM. Keith Turner is the principal coater operator. His responsibilities include development of IVD coating procedures for individual parts as well as coating production parts. Reed Dentinger, a new IVD operator, and Keith participated in all activities for the 2 weeks. Oscar Layton, another new operator, participated in all activities the first week. Other SM personnel received training on the basis of their availability.

The Alameda Naval Aviation Depot sent Ray Vermillion, their IVD aluminum process engineer, and John Foster, their coater operator to SM to participate in the IVD training sessions during this period (Reference 21).

The IVD aluminum process is relatively new for both SM and Alameda personnel. Therefore, SM requested a concentrated training effort directed at the coating process and equipment. During the first week, 32 hours of classroom and "hands on" operator training were provided to five operators. Emphasis was placed on coater operation, maintenance, and troubleshooting. Coater operations and maintenance items reviewed are listed in Tables 25 and 26, respectively.

In addition, two electricians, one mechanic, and one engineer received 4 hours of preventive maintenance training. One of the electricians received an additional 2 hours of individual training.

During the two weeks at SM, several coater problems were diagnosed and resolved. The problems and solutions are listed in Table 29.

TABLE 29. COATER PROBLEMS DIAGNOSED AND RESOLVED AT SACRAMENTO AIR LOGISTICS CENTER.

Problem	Corrective Action
• False Indication of Proper Pumpdown	Replace Defective Cold Cathode Gauge
• Coating Adhesion	Replace Defective Cold Cathode Gauge
• Wire Feed Rate Unknown	Calibrate and Set Wire Feed Rate
• Cold Cathode and Chamber Gauges Zero Off	Explain and Demonstrate Procedure to Zero Gauges
• Process Cycle Not Optimized	Incorporate Convective Cooling Into Process Cycle More Efficiently
• Standby Pumping Procedure Not Known	Explain and Demonstrate Standby Pumping Procedure for Process Cycle and for Troubleshooting/Maintenance
• Some Lubrication Points Missed	Correct Lubrication Chart

During the second week, coating procedures were developed and verified for the SM parts shown in Table 30.

TABLE 30. DEVELOPMENT AND VERIFICATION OF COATING PROCEDURES FOR PARTS AT THE SACRAMENTO AIR LOGISTICS CENTER.

Part Number	Name
–	Gasoline Generator Cover
55478	Port Cap
–	Hot Air Valve
18997	C-5 A/C Cover
MSQ-T13 Parts	Mounting Bar (Steel)
MSQ-T13 Parts	Contractor Chassis (Steel)
	2 Plates
	1 Bracket
MSQ-T13 Parts	Miscellaneous (Aluminum)
	7 Plates and Brackets
	4 Shims
	16 L-Brackets

All of the parts were vapor-degreased, stripped of cadmium if plated, grit blasted with 220 aluminum-oxide grit, and blown off with dry, filtered air. The parts were hung horizontally off the stationary rack 10-12 inches above the boats where size and configuration allowed. Adhesion of the IVD aluminum coating was verified by glass-bead peening the parts at 30-40 psi. The thickness of the coating was measured using a Zorelco 727 gauge. The Zorelco 727 was calibrated using a bare spot for the zero-calibration point and a 0.001-inch thick plastic shim for the upper-calibration point.

The Gasoline Generator Cover is a steel sheet metal box 10 x 8 x 8 inches. Both the inside and outside surfaces of the box were coated. The box has two openings, 90 degrees apart, through which the inside was coated. One opening is 6.4 x 7.3 inches, and the other opening is 5.2 inches in diameter. The box is a formed enclosure with a 0.5-inch wide fold tack welded on some edges of the box. Faying surfaces are created in the tack-weld area that are difficult to clean by vapor degreasing and grit blasting. A procedure was developed to vapor-degrease, high-temperature bake, and grit-blast before acceptable coating adhesion was obtained. Without the bake step, outgassing, from moisture or oil entrapment between the faying surfaces, caused nonadhesion of the IVD aluminum inside the box. The box was hung horizontally with the largest opening directly above the boats during coating. After the first coating cycle, the box was rotated 90 degrees and coated through the smaller opening.

Complete IVD aluminum-coating coverage, even into corners on the inside of the box, and excellent coating adhesion were obtained on the Gasoline Generator Cover. SM plating shop personnel were pleased with the IVD aluminum-coated part as cadmium plating did not cover the inside corners.

Several meetings were held with the SM hydraulic shop to review cadmium-plated candidate parts for conversion to IVD aluminum. The hydraulic shop has many potential applications for IVD aluminum coating. The 55478, 59877N, and 67908 Port Caps were selected for demonstration.

The 55478 Port Cap is typical of many parts at SM; namely, small, hollow steel parts where masking is required for either one or more external surface; the ID of the part; or opening to the ID for both grit blasting and IVD aluminum coating. The challenge at SM is masking efficiency for this type of part rather than coating the masked parts. Hard masking has not been designed for these parts and the parts are generally difficult and time-consuming to mask with aluminum foil. (Tapes cannot be used, since outgassing would be excessive and cause coating adhesion problems.)

Daniel Siroky, Liaison engineer from the OC-ALC supplied a high-temperature plastic cap for evaluation as a mask to protect a lapped external surface and the ID of the 55478 Port Cap. The plastic cap greatly simplified masking of the part.

Time prevented processing of the 59877N and 67908 Port Caps. However, since they are similar to the 55478 Port Cap, the same masking and coating procedure were recommended to SM.

The other Table 30 parts were coated successfully using standard procedures. Attention was called however to the MSQ-T13 aluminum-alloy parts. Aluminum-alloy parts are processed using coating-cooling cycles to minimize heat input to the part and potential mechanical property degradation. The MCAIR process for coating small aluminum-alloy parts was explained and demonstrated.

The Zorelco 727 coating thickness gauge was evaluated by measuring coating thicknesses on several alloy-steel coupons. These measurements tracked within nine percent of readings taken with the WR Minitest 4000 instruments. MCAIR believes that the Zorelco 727 unit is adequate for use at SM.

MCAIR concluded the visit with a debrief to SM personnel. The debrief covered visit proceedings and offered the following recommendations:

- Construction of an acoustic wall within the IVD coating room. The noise level in the room is high. An acoustic wall would block off noise generated by the mechanical pump.

- Placement of a Rockwell Hardness Tester in the IVD coating area to measure the hardness of aluminum-alloy parts after coating. It is inefficient to ship parts between major areas of the building for hardness measurements.

- Procurement of a barrel accessory for precleaning small parts in the grit blaster and one for peening coated parts in the glass- bead peener.

- Procurement of stainless-steel foil for masking. The foil can be cut to size, rolled up, and inserted into cylindrical cavities. The foil will spring out masking the interior surface.

4. Oklahoma City (OC)-ALC Demonstration/Assistance

MCAIR provided assistance to the OC-ALC effort to implement the use of IVD aluminum coating as a replacement for cadmium during a 2-week period beginning 11 May 1992. Coating procedures were examined, masking techniques discussed, and coating thickness verified on several parts. In addition, MCAIR provided training to OC personnel.

Jeff Marnix, IVD Process Engineer, is responsible for the coater operation/coating process at OC. Jeff and two principal IVD operators, John White and Joe Steele, participated in the IVD process and equipment training. Other OC personnel received operator or maintenance training on the basis of their availability. During the visit, emphasis was placed on coater operation, maintenance, troubleshooting, masking, and coating parts. Coater operation and maintenance items that were reviewed are listed in Tables 25 and 26, respectively. During the 2 weeks at OC, several coater problems were diagnosed and resolved. The problems and solutions are listed in Table 31.

OC-ALC eliminated cadmium plating in November 1991. Most of the former cadmium-plated parts are now being processed with IVD aluminum. The parts listed in Table 32 were identified as parts that require extensive localized masking prior to being coated.

OC currently masks these parts with aluminum foil. They realize that reusable, hard masks would be more efficient, but lack of funds/personnel prevent immediate implementation. MCAIR determined that hard masking is feasible for all of the Table 32 parts and recommended its use to improve future productivity.

MCAIR recommended the installation of a cryopump in the OC-ALC coater. The time required to pump the OC coater from atmospheric pressure down to the normal evacuation pressure of 9×10^{-5} torr was 60 to 90 minutes, which is typical. Pumpdown times vary depending on coating buildup in the coater and on the parts rack, humidity, and length of time the parts rack sits outside the coater. With a cryopump, the pumpdown time is typically 25 to 40 minutes.

4. Ogden (OO)-ALC Demonstrations/Assistance

MCAIR assisted the OO-ALC effort to implement the use of IVD aluminum as a replacement for cadmium plating on OO parts during a 2-week period beginning 10 June 1992. Coating procedures were examined, masking techniques discussed, and coating thickness verified on several parts. In addition, MCAIR provided training to OO personnel.

OO requested additional training to better understand the coating process and equipment. Mark Child, IVD Process Engineering, is responsible for the coater operation/coating process at OO. Mark and two principal IVD operators, Richard Newton and Amy Nickerson, participated in the IVD process and equipment training. Richard is responsible for coating procedural development as well as coating production parts. Jack Summers is the principal IVD electrician at OO and actively participated in the 2-week training period. Six other OO

TABLE 31. COATER PROBLEMS DIAGNOSED AND RESOLVED AT OKLAHOMA CITY AIR LOGISTICS CENTER.

Problem	Corrective Action
• Diffusion Pump Kick-Off	Inspect and Lubricate Roughing Valve O-Ring and Adjust Air Pressure to Roughing Valve
• Diffusion Pump Remains on at Foreline Pressures Above 500 Microns	Adjust Set Point to Turn Diffusion Pump Off if Foreline Pressure Rises Above 500 Microns to Assure Safe Operation
• Incorrect Chamber Thermocouple Gauge Set Point for Proper Automatic Pumpdown of Coater	Set Point Could Not Be Adjusted. There Is Either a Defective Thermocouple Gauge (No Spare Available for Replacement) or a Defective Thermocouple Gauge Circuit/Readout. OC Is to Identify the Specific Problem When a Replacement Thermocouple Gauge Is Obtained.
• Incorrect Chamber Thermocouple Gauge Zero Setting	Set Mechanical Zero But Could Not Adjust Pressure Readout to Zero at High Vacuum (Defective Gauge or Zero Potentiometer)
• Incorrect Ion Gauge Pressure	Set Ion Gauge Emission Current to Correct Value
• Chamber Pumpdown Not as Low as Recommended	Adjust Ion Gauge Set Point to Correct Value to Achieve Desired Pumpdown Pressure
• Pressure Slightly Low During Glow Discharge Cleaning	Adjust Argon Pressure, Flowrate, and Pressure Control Set Point to Improve Glow Discharge Cleaning
• Pressure Variations During Glow Discharge Cleaning	Adjust Gain of Pressure Control System to Reduce Noise Effects of High Voltage Arcs in the Coater
• Boat (Evaporator) Operation in Need of Fine Tuning	Correct Potentiometer Zero, Adjust Warmup Potentiometer to Fixed Value, and Adjust Run Potentiometers to Heat Boats Uniformly
• Some Boats Too Hot in Ground Side Boat Clamps	These Boats Are Not Being Cooled Properly. A Silver Foil in Heat Transfer Path Between These Boats and Water Cooling System Has Slipped. OC to Disassemble Ground Side of Evaporation System to Clean and Adjust Silver Foil Placement
• Wire Feed Jams Due to Melted Coating on Wire Feed Tips	OC to Correct Ground Boat Clamp Cooling Problem (Some Boats Too Hot in Ground Boat Clamp)
• Wire Bite Engagement Off	Adjust Wire Feed Bite for Uniform Feed of Aluminum Evaporate
• Wide Variation in Wire Impingement Point Onto the Boats	Straighten Wire Feed Tubes and Adjust Wire Feed Impingement Point Onto the Boats
• Moisture Adsorption by IVD Coating on Door Shield Delaying Coater Pumpdown	Door Shield Water Valve Not Closing Completely. Add Filter in Water Supply to Remove Sand Contamination. Clean or Replace Door Shield Water Valve/Solenoid as Required
• With High Vacuum Valve Open, Pressure Relief in Hydraulic System Leaking	Adjust Pressure Relief Setting to Remain Closed During Normal Operation
• Delay in Coater Pumpdown Due to Thick Aluminum Coating on the Standard Rack	OC-ALC Does Not Have a Tank Large Enough for Chemical Stripping the Standard Rack. OC-ALC Will Explore Mechanically Stripping or Chemical Stripping in an External Facility.

TABLE 32. EXTENSIVE MASKING REQUIREMENTS BEFORE IVD ALUMINUM COATING.

Part Number	Name
502184	Housing Assembly Gearbox Bearing
502366	Housing Assembly Gearbox Bearing
739635	Housing Gearbox Drive Bearing
666882	Housing Assembly Gearbox Bearing
618865	Housing Assembly Gearbox Bearing
502178	Housing Bearing Inner Gearbox

electricians attended a 4-hour training class directed at the IVD coating equipment and process. Other OO personnel received operator or maintenance training on the basis of their availability.

During the first week, emphasis was placed on coater operation, maintenance, and troubleshooting training. Coater operations and maintenance items reviewed are listed in Tables 25 and 26, respectively. During the two weeks at OC, several coater problems were diagnosed and resolved. The problems and solutions are listed in Table 33.

MCAIR recommended the use of production procedure cards at OO. Richard Newton received copies of WR procedure cards during his visit to WR in April. Since OO has two IVD aluminum coaters, Richard requested that the operating parameters be made identical to enable common procedure cards for both coaters. Boat-rack speed and wire-feed rates were adjusted to be the same for the two coaters. For wire feed rate adjustment, there is a difference in the control potentiometers for the two coaters. An OO electrician was trained using a "length of fed wire versus time" adjustment procedure.

MCAIR was asked to assist OO with their initial removal and cleaning of a diffusion pump. OO had observed earlier what appeared to be water droplets on the bottom of the high-vacuum valve above the diffusion pump on Coater 2. MCAIR also observed similar droplets on the bottom of the high- vacuum valve during an o-ring inspection in the high-vacuum valve. Since the high vacuum valve is normally covered with oil, it was difficult to tell whether the droplets were oil or an oil and water mixture. Water leaks in the diffusion pump cause delayed

TABLE 33. COATER PROBLEMS DIAGNOSED AND RESOLVED AT OGDEN AIR LOGISTICS CENTER.

Problem	Corrective Action
• Blower Oil Level Low	Fill Oil Reservoirs to Full Mark
• Ion Gauge Meter Loose in Ion Gauge Controller	Remove Ion Gauge Controller and Tighten Nuts Holding Meter
• Foreline Vent Valve Leaking	Replace Defective O-Ring
• Silver Foil in the Heat Transfer Path Between the Ground Side Boat Clamp and Water Cooling System Slipped at Some Boat Stations	Disassemble the Ground Side Boat Clamps, Clean, Reposition the Silver Foil, and Reassemble the Boat Clamps to the Water Cooling System
• Loose Clamps Causing Improper Boat Cooling at Two Boat Stations	Tighten Bolt Clamp Holder Bolts
• Convectron Gauge Zero Slightly Off, Affecting Glow Discharge Cleaning and Coating Pressure	Adjust Zero Potentiometer to Set Zero When System Pressure Is Less Than 5 x 10^{-4} Torr
• Thermocouple Gauge Zero Off Affecting Pressure at Which Rough Pumping Stops and High Vacuum Pumping Starts	Adjust Zero Potentiometer to Set Zero When System Pressure Is Less Than 5 x 10^{-4} Torr
• Part Rack Sets Outside of Coater for Extended Periods Absorbing Moisture	Keep Rack in Coater and Coater Evacuated When Coater Is Not Being Used
• Glow Discharge Cleaning/Coating Pressure Low in Coater No. 2	Adjust Hydraulic Pressure Control to Desired Pressure for Improved Glow Discharge Cleaning and for Better Coating Distribution
• Cannot Install Thumbscrews That Support Boat Shield	Remove IVD Aluminum Coating From Nuts
• Diffusion Pump Kick-Off Due to Incorrect Zero Setting	Adjust Zero Potentiometer to Correct Setting
• Pipe/AN Fitting on Two Wire Feeders Damaged	Retap Pipe Threads in Wire Feeder Assembly and Install New Pipe/AN Fittings
• Boat Operation Not Optimized	Calibrate Boat Power System by Adjusting Boat Card Bias and Gain Versus Run Potentiometer Setting to Produce Identical Boat Voltages at All Boat Stations

coater pumpdown, increased backstreaming of diffusion pump oil into the high vacuum valve area, and increased diffusion pump oil loss from the diffusion pump. All of the symptoms of a small water leak existed.

The diffusion pump was removed and disassembled from Coater 2. The diffusion pump components were then vapor-degreased to remove silicone-based diffusion oil residue. Baked-on aluminum soils were removed by glass bead peening the components. A helium leak check of the diffusion pump cold cap revealed that a very small water leak was occurring at a braze joint in the water line to the cold cap. After the joint was rebrazed, a helium leak check of the water line/cold cap verified it was leak free.

Since the diffusion pump was off the coater, the high-vacuum valve sealing disk, high-vacuum valve, and elbow area between the coater and high-vacuum valve were also cleaned. The oil/aluminum dust mixture was easily removed from the valve disk and in the high-vacuum valve area. However, a layer of aluminum coating saturated with diffusion pump oil on the elbow area required laborious removal with a scraper. The elbow area is shielded from coating when the stationary rack is used in the coater. However, when the rotary rack is used, coating wraps into this area. MCAIR recommended that a shield be installed in the elbow of the coater to eliminate the coating buildup on the elbow shell. The coated shield can then be removed as required, and excess coating stripped off.

During coating, the ends of the boats are normally maintained at temperatures below the melting point of aluminum by maintaining a good heat transfer path between the boat and the water cooling system. MCAIR observed that a silver foil used to maintain hard contact between the water cooling system and boat clamp had slipped out of position at two boat stations. With the foil displaced, the heat transfer path between the boat and the water cooling system had degraded allowing the end of the boat to exceed the melting point of aluminum. This causes excessive erosion of the copper boat holder as molten aluminum washes off the boat onto the boat holder. It can also melt aluminum particles on the wire feed tip causing wire feed jams.

The seven-boat evaporation system was disassembled and cleaned. The silver foil was cleaned and positioned correctly before the system was reassembled. Boat overheating did not reoccur.

OO was coating one B-52 Main Cylinder Assy, P/N 5-85123-6, at a time on the rotary rack upon MCAIR's visit. MCAIR suggested coating two at a time.

However, an electrical a short occurred while coating the two parts which placed the parts at the same electrical potential as the coater structure. The condition basically prevents the aluminum coating from being applied in an ion vapor deposition mode resulting in poor coating adhesion. The short was traced to movement of an insulator/shield assembly. Suggestions were made to cut the insulator into pieces and bolt down the pieces to prevent movement. Several sets of parts were then successfully processed.

The C-5A Main Roll Pin, P/N 4G 11439-113A, has a bottle shaped recess in one end that is 5 inches in diameter at the top, 5.5 inches in diameter at the bottom, and 5 inches deep. OO had not been successful in coating the recess area. MCAIR suggested changing the part's orientation during coating. The recess area of the part was directed toward the boats and the boat rack speed was reduced during coating to allow additional time to coat into the recess. Since the external surface is threaded, a nut was used to shield the threads from excessive coating. When the part was turned over for additional coating, the nut was removed, and the threaded area as well as the remainder of the part were coated. Proper orientation allowed complete coverage of the C-5A Main Roll Pin.

MCAIR observed conditions for both OO coaters such as dark coating and/or excessive evacuation times which result from coating buildup and moisture adsorption. MCAIR recommended the installation of cryopumps to reduce pumpdown times and improve coating appearance and quality as well as periodic coating removal from the chambers.

One of the OO coaters has a baffle in the foreline of the diffusion pump which conserves the consumption of the relatively expensive silicone-based diffusion pump oil. OO was given information to add a foreline baffle to the other coater.

MCAIR provided a list of additional components to convert the OO single-barrel accessory to a dual-barrel accessory. Also, the addition of a second rotary parts rack to address the increasing IVD aluminum workload at OO was discussed. MCAIR also recommended the purchase of extra spare parts to maintain a two-coater production status at all times.

As OO responsibility includes overhaul of aircraft landing gears for several large aircraft, there are several landing gear components that are too large to fit in the IVD coater. These components are still being cadmium-plated. OO is exploring other coating processes or larger IVD equipment for these parts.